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PHYSIOLOGY

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SCIENCE TEXT-BOOKS.

AN ELEMENTARY

TEXT-BOOK OF PHYSIOLOGY

BY

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PREFACE TO SECOND EDITION.

In preparing a second edition of this text-book, the demand for which is gratifying evidence of its usefulness, I have carefully revised the whole of the book, recast several of the original sections, and added much new matter, as well as several new engravings. In doing so I have kept in view the requirements of the Science and Art Examinations (Elementary and Advanced Stages), and of the Local Examinations of the Universities. The candidate in the Elementary Stage of the former may safely neglect the paragraphs that are printed in a smaller type.

J. M'G.-R.

GLASGOW, *November*, 1892.

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Anatomical Plate illustrating—
(1) The terms applied to the various Parts of the Human Skeleton;
(2) Terms applied to the Muscles of the Human Body,
at end of volume.

PHYSIOLOGY.

INTRODUCTION.

Biology, from the Greek *bios*, life, and *logos*, a discourse, is the term applied to the science which considers and investigates living structures, from the highest to the lowest forms. All living structures must evidently be studied from two sides, their form, their build, must be examined, and then the living processes which go on within them must be observed. Hence the science of biology has two great branches, that of **Morphology** (Greek *morphe*, form, and *logos*, a discourse), the study of the form and build of living structures, and **Physiology** (Greek *phusis*, nature, and *logos*), the study of the living processes that go on in the structures.

As biology treats of all living structures whatsoever, it includes not only man and the higher animals, but all animals down to the most minute and seemingly insignificant. It includes all plants, and every form of vegetable life, and it also embraces the multitude of minute living things that the microscope reveals, such as what are called "germs," concerning some of which it is difficult to say whether they belong to the animal or vegetable kingdom. The science which limits itself to the consideration of vegetable life is called **Botany** (Greek *botane*, a plant), and the science which limits itself to the consideration of animal life is called **Zoology** (Greek *zoon*, an animal, and *logos*). Botany and zoology are thus simply parts of the wide science, biology, which includes them both. The student of plants has always to consider two things concerning them, namely, their form and build, that is, their morphology (plant morphology) and the living processes that go on within them, that is their physiology, plant or vegetable physiology. In the same way the student of animal life must consider the form and build of the animals he studies, that is to say, the different parts and organs of which their bodies are made up, their morphology, and secondly the processes that go on within them characteristic of life, that is, their physiology. Thus we have animal morphology and animal physiology. In the same way we have human morphology and human physiology. Instead of the term morphology the term **Anatomy** is very generally used. It is derived from the Greek *ana*, up, and *temno*, I cut, and would thus mean the science of cutting up or of dissection. The knowledge of the form and build of animal bodies and vegetable structures is chiefly gained, of course, by taking the bodies to pieces in a scientific way, that is, by anatomy. So the word which properly signifies the scientific method of obtaining information of a morphological kind has come to be generally employed to mean the mass of knowledge thus obtained. So one speaks of anatomy and physiology when more strictly one ought to say morphology and physiology. Let us, however, take the word anatomy, as it is thus generally employed, and we now know that human anatomy deals with the form and build of human bodies, with the parts and organs of which they are made up, and the method in which they are arranged, as revealed by dissection and other methods of observation. One of the other methods of observation employed is the use of the microscope. By its means one is able to make out much more accurately than by the unaided eye what an organ or part of the body is made up of. This is really only a very fine method of dissection. So we speak of the *minute anatomy* of a part of the body, meaning thereby the structure of that part of the body as revealed by the microscope. A special word is employed for this, namely **Histology** (*histos*, a web, and *logos*), but it is simply a refinement of anatomy. We know now, also, that human physiology deals with the normal processes that go on within the living human body. It studies the way in which the various parts work together, bringing to its aid in the investigation any scientific method that seems likely to help in obtaining information.

This is the subject, then, with which this text-book has to deal, **Human Physiology,** or the science of the normal processes that go on in the living human body, the science which treats of the work the various parts of the body perform, and which considers the results of the harmonious working together of all the different parts.

But it is plain that we cannot properly understand the physiology of the human body without reference to the form and build, to the *anatomy*, of the body and its various organs, and thus we shall have to note the main anatomical facts regarding a part of the body before going on to consider the work which the part does, the duty it performs, just as an engineer could not properly understand the working of his steam-engine unless he were well acquainted with its various parts and the manner in which they were fitted together.

From one other point of view, differing from the anatomist's or the physiologist's, may the human body be regarded, namely, from the chemist's. The chemist takes a piece of rock, splits it up and analyses it, telling soon of what substances it is composed. A spring is found bubbling up from the earth; the chemist takes a sample of the water, and is able to state the various substances it contains in solution and their relative quantities. A plant, a fruit, &c. may be submitted to his examination, and their chemical composition determined. In the same way the chemist may treat the body of an animal and analyse it as he would any other substance. He can determine what chemical elements enter into the composition of blood, bone, and flesh, as readily as he can analyse a mineral water, a piece of rock, or a handful of earth. But inasmuch as the body or part of it must be dead before it can be submitted to such an examination, the information yielded is of limited value. The results will be briefly stated.

CHAPTER I.—THE CHEMICAL CONSTITUTION OF THE HUMAN BODY.

Chemical Elements found in the body.—All the various complex substances found in nature can be reduced by chemical analysis to simple substances, and when they have been reduced to their simplest forms and cannot be any further split up, there remain seventy elements. By combinations of these seventy elements, of various kinds and in various proportions, all the substances known to exist in the world of nature are built up.

A human body, when dead, may be submitted to chemical examination just as a handful of earth, a piece of rock, or any other substance may be. When that has been done, it is found that blood, muscle, nerve, bone, skin, hair, teeth, &c., may also be reduced to similar elements, that, in fact, the human body is built up of a few of the same seventy elements that are found in nature. Of the seventy elements only fourteen are found in the human body, namely, **oxygen, hydrogen, nitrogen, chlorine, fluorine, carbon, phosphorus, sulphur, silicon, calcium, potassium, sodium, magnesium,** and **iron.** Some of these elements, as they exist in their elementary form, are gases, others are metals, while the remainder are non-metals. This may be shown as follows:—

Elements found to exist in the Human Body.

Oxygen	Gases.
Hydrogen	
Nitrogen	
Chlorine	
Fluorine	
Calcium	Metals.
Potassium	
Sodium	
Magnesium	
Iron	
Carbon	Non-Metals.
Phosphorus	
Sulphur	
Silicon	

Besides these, excessively minute quantities of other elements, such as manganese, copper, lead, &c., have been found, but probably they are only accidentally or temporarily present, and did not enter into the actual constitution of the body. They may, therefore, be neglected. Silicon is in a similar position though it appears on the list.

It is interesting to note the proportion in which these various elements are present, and this is shown in percentages in the following table:

Oxygen ..	62·430	per cent.
Carbon ...	21·150	,,
Hydrogen	9·865	,,
Nitrogen	3·100	,,
Calcium	1·900	,,
Phosphorus	0·946	,,
Potassium	0·230	,,
Sulphur	0·162	,,
Chlorine	0·081	,,
Sodium...	0·081	,,
Magnesium	0·027	,,
Iron ...	0·014	,,
Fluorine	0·014	,,
	100·000	

Oxygen, hydrogen, and nitrogen, as we see from the preceding table, are gases in their uncombined state, and yet they form three-fourths of the weight of the whole human body. Carbon is a solid. Charcoal, lampblack, black-lead, are impure forms of it. It forms more than a fifth of the whole weight of the body. Carbon and the three gases named thus form over 96 per cent of the total weight of the body.

Chemical Compounds found in the body.—It is necessary very carefully to note that, with slight exceptions, none of these elements exist *in their elementary form* in the body; they are combined with one another in various ways and proportions to build up more or less complex substances, differing widely from the elements of which they consist. The slight exceptions are oxygen, hydrogen, and nitrogen. Though the bulk of all three exists in combinations of various kinds, yet a small quantity of oxygen exists uncombined, but in solution, in the blood, a small quantity of nitrogen is also found in solution in the blood, and small quantities of all three exist free in the intestinal canal.

Water.—Now oxygen and hydrogen unite to form water; and water is found in the human body to the extent of over 60 per cent.

Inorganic Salts.—Further, a large number of the elements named are found uniting with one another to form inorganic salts, salts found existing in nature, which do not need the agency of any living thing, any organized structure, to cause them to combine, but do so simply by the force of chemical affinity.

The best example of this kind of compound is common salt, a compound of sodium and chlorine, called, therefore, in chemical language, chloride of sodium. It is found in all the tissues and fluids of the body, and is one of the most important inorganic substances the body contains, and is absolutely necessary for continued existence.

Chlorine, besides uniting with sodium, forms a salt in conjunction with potassium, the chloride of potassium, and forms with nitrogen and hydrogen the chloride of ammonium, ammonia being a compound of nitrogen and hydrogen. These are found in the body.

Other salts are found in the body, of great importance being those formed by a combination of phosphorus with sodium, with potassium, with calcium, and with magnesium, forming the phosphate of sodium, phosphate of potassium, phosphate of magnesium, and phosphate of calcium (phosphate of lime). This last, phosphate of calcium (that is, phosphate of lime), is the most abundant of the salts of the body. It forms more than half of the bones, and is found in considerable quantity in teeth, and it exists in other solids and in fluids of the body. It is present in milk to the extent of $2\frac{1}{2}$ per cent. Associated with it in bones and teeth is a compound of calcium with carbon and oxygen, carbonate of lime.

Sodium combined with carbon and oxygen exists in the body as carbonate of sodium, and with sulphur and oxygen as sulphate of sodium.

Potassium also exists as sulphate of potassium.

Fluorine and calcium are found united as fluoride of calcium in the bones and teeth, though in very small amount.

If all these compounds, forming salts or mineral matters, that exist in the body, be summed up together, they are found to constitute about six per cent of the whole body weight.

Thus, so far as we have gone, we see the human body consists of:—

Water about	...61 per cent.
Salts or Mineral Matters ...	... 6 " "

Namely—**Chloride of Sodium.**
" of Potassium.
" of Magnesium.
" of Ammonium.

Phosphate of Lime.
" of Sodium.
" of Potassium.
" of Magnesium.

Carbonate of Lime.
" of Sodium.

Sulphate of Potassium.
" of Sodium.

Fluoride of Calcium.

A compound of hydrogen and chlorine, hydrochloric acid, is found existing as such in the digestive juice of the stomach.

Organic Compounds.—Now over and above these substances there exists in the human body a series of compounds not found in the lifeless or inorganic world, substances formed of the union of the same elements that have been named, but which require for their compounding the agency of living structures. For that reason these compounds are called **organic.** Moreover, man and the lower animals cannot compound them, or build them up from the elements; that is done by plants. Man and the lower animals take the organic materials they require from the vegetable world, and so the structure of the animal kingdom, including man as the most imposing portion of the edifice, rests upon the vegetable kingdom as its foundation. The organic materials which animals and men take from the vegetable kingdom they build up into still more highly organized forms in their own bodies.

The organic materials found in the human body fall principally into three classes:—

Proteid or Albuminous Substances.
Carbo-hydrates (that is, Starches, Sugars, and Gums).
Fats.

The elements built up into proteids are carbon, hydrogen, oxygen, and nitrogen, with sulphur; the elements built up into carbo-hydrates are carbon, hydrogen. and oxygen; the elements built up into fats are also carbon, hydrogen, and oxygen. The important distinction between the first and the other two classes is that proteids contain the element nitrogen which the others want. Proteids are, therefore, called **nitrogenous,** and the others **non-nitrogenous** substances. Further it will be noted that carbo-hydrates and fats are built up of the same three elements, carbon, hydrogen, and oxygen; the difference between the two classes consists not merely in the proportions in which the three elements are combined. but also in the manner of the combination, just as stone, wood, and lime may be built up into two houses of very different form, and not the least resembling one another. It may now be convenient to put in tabular form the knowledge thus far gained.

The human body contains thirteen elements built up into various compounds, as follows:—

		Built up of
Inorganic—		
	Water...	Hydrogen and Oxygen.
	Salts ...	Hydrogen, Oxygen, Nitrogen, Carbon, Calcium, Phosphorus, Potassium, Sodium, Sulphur, Chlorine, Magnesium, Iron, Fluorine.
Organic—		
Nitrogenous	Proteids	Carbon, Hydrogen, Oxygen, Nitrogen, and Sulphur.
Non-nitrogenous	Carbo-hydrates	Carbon. Hydrogen. Oxygen.
	Fats ...	Carbon. Hydrogen. Oxygen.

We must consider the organic substances for a little.

Proteids consist, as already mentioned, of carbon, hydrogen, oxygen, nitrogen, and sulphur. The type of proteids is egg albumin, white of egg. These proteid or albuminous bodies are found in muscle, in nerve, in glands, in blood, and in nearly all the fluids of the body. The albuminous body of muscle is called **myosin,** that of the fluid part of blood is **serum-albumin,** that of coagulated blood is **fibrin,** the red corpuscles of the blood are formed of **hæmoglobin,** which contains an albuminous body.

Milk contains two albuminous bodies, the chief of which is **casein,** which forms the curd, and is the main constituent of cheese. Proteid bodies occur in various forms in vegetable structures; the proteid of cereals, wheat, corn, &c., is called **glutin,** that of peas is **legumin.**

Other substances much resembling proteids exist. Thus, in bones, and connective tissues like tendon and skin, there is such a substance, which, on boiling, yields **gelatin.** Gristle (p. 37), yields another called **chondrin.**

Of proteid substances a human body is estimated to yield on an average about 18 per cent.

Carbo-hydrates are formed of carbon, hydrogen, and oxygen, the last two being in proportions to form water. Starch is a carbo-hydrate, and is found in the body in the form of **glycogen** or animal starch, supposed to be formed by the liver (see p. 121). Sugar is another of this class, and is found as **grape-sugar** in blood and liver, **muscle-sugar** or **inosite** in muscle, and **lactose** or **milk-sugar** in milk.

This class exists largely in the vegetable kingdom. Thus potatoes, rice, sago, &c., consist largely of starch. Sugar is found in fruit as **laevulose**: there is **grape-sugar**, of which honey mainly consists, derived from the sweet juices of fruits and flowers, and **cane-sugar**. **Gum** and **cellulose**, obtained from plants, are also carbo-hydrates.

The carbo-hydrates in the body are estimated at a fraction of one per cent of the total body weight.

Fats are formed of carbon, hydrogen, and oxygen, in which the two latter are not in proportions to form water. There are three kinds of fat in the body—**stearin**, of which ordinary tallow candles are made, **olein**, the chief ingredient of olive-oil, and **palmitin**. The fat of the human body consists of a mixture of these three, and is liquid at the ordinary temperature, the olein keeping the other two in solution.

The body of an average man contains about 16 per cent of fats.

Now, while it is said that a human body consists of so much water, so much salts, so much proteid material, so much carbo-hydrates, and so much fat, it is not to be supposed that these exist in a condition easily separable from one another.

Take a piece of the red flesh (muscle), it does not only contain proteids but also water, salts, carbo-hydrates, and fats. They are blended or mixed together, as it were, in the muscle, and in different cases the amount will vary. Fat will exist in the muscle even though it be not visible to the naked eye; the microscope will show minute fat cells (see p. 36) between and among the muscular fibres.

It requires to be noted that, though the proteids are the principal kind of nitrogenous substances existing in the body, they are not the only ones.

The ferments concerned in digestion, the ptyalin of the saliva (see p. 111), the pepsin of the stomach juices (see p. 112), &c., are nitrogenous also. The colouring matters of the body, that of the blood and red flesh, and those of the bile are also nitrogenous substances. Moreover, as a result of the tear and wear of the body, and the consequent breaking down of the tissues that constantly goes on, a variety of substances is formed from proteids also containing nitrogen. Thus there can be extracted from ordinary red flesh, by means of water, a variety of nitrogenous substances, of which kreatin, kreatinin, sarcin are the names of some. On this account they are called **extractives.** It is the presence of some of these that gives to flesh its peculiar flavour.

Two other important substances produced from the breaking down of nitrogenous substances, and containing nitrogen, are *urea* and *uric acid*, found in the urine. Though found in the body, they are to be regarded as unavoidable rather than necessary constituents, since they are the result of tear and wear. In nerve tissues, as another example, are found substances called protagon, cerebrin, &c., supposed to result from nervous activity, which are also nitrogenous. Just in the same way the changes undergone by sugars, fats, &c., in the body, produce a series of substances that need not be named here. Though constantly found, they are not essential constituents of the body.

Briefly, then, we may put the matter thus, the human body is composed of thirteen elements, built up into compounds. The compounds may be grouped into the following classes—water, salts, proteids, carbo-hydrates, and fats. These five classes of compounds, existing as such in the body, are called the **proximate principles** of the body, and the proportion in which they exist is summarized in the following table:—

PERCENTAGES OF PROXIMATE PRINCIPLES IN THE BODY.

Water, ...	61·0	per cent.
Salts, or mineral matters, ...	5·5	,,
Proteids, ...	18·0	,,
Carbo-hydrates, ...	0·1	,,
Fats, ...	15·4	,,
Total, ...	100·0	

CHAPTER II.—ELEMENTARY STRUCTURES.

It has been mentioned (p. 16) that by means of the microscope the minute particles of which the various parts and organs of the body are made up can be discovered. The ultimate structures into which, by the aid of this instrument, the body or its organs can be reduced may be considered as the structural elements of the body, just as carbon, oxygen, nitrogen, &c. are the chemical elements. Some of these will be described in this chapter.

CELLS.

The ultimate elements of which the body is composed consist of masses, microscopic in size, of a jelly-like material called **protoplasm.** In its simplest form, protoplasm is a homogeneous-looking substance, semi-fluid, without apparent differentiation of parts. It may also appear studded with fine or coarse granules, or exhibiting a fine or coarse, more or less irregular, network. Often it exhibits little spaces, vacuoles, filled with fluid. In the living state it possesses the power of spontaneous movement, evidenced by change of form. Thus at one moment the little mass is more or less spherical, then it becomes irregular in outline by one or more processes of its substance being pushed out. Moreover, by pushing out one process in one direction and retracting another, it can change its place (fig. 1). Now such minute masses of protoplasm are found forming the whole substance of certain microscopic living things. The **amœba** of stagnant pools is such an organism, living an independent life, growing by enveloping with its processes particles in the water with which it comes into contact, incorporating them with itself and building them up into living protoplasm like itself. The material fit for its nourishment, which it comes into contact with, it builds up, not at a bound, but in various stages, and as a result of its activity waste substances are produced. Thus in such a little mass of protoplasm, there are found not only the substances of which the protoplasm properly consists, namely, proteids chiefly, and also carbo-hydrates fats and salts, but also other substances, in but not of the protoplasm, lodged in the meshes of its net-work or in vacuoles, some of which are in process of being built up into living protoplasm, while others are the waste products of its activity. Now while there are found, in the lowest realms of animal life, organisms consisting of nothing more than has been described, there are others similar to them, which possess a small body in the interior called a **nucleus**. This is spoken of as nucleated protoplasm.

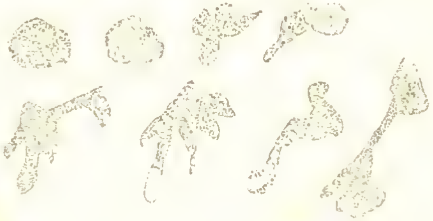
Fig. 1.—White Blood Corpuscle. Its successive changes of shape.

When the animal body is carefully examined, in all the tissues there are found masses of nucleated protoplasm of various sizes and shapes. In all essential features they resemble the structures described. Such bodies are called cells. In many of them the nucleus is finely granular or reticulated in appearance, and on the threads of the mesh-work may be one or more enlargements, called nucleoli. In some cases the protoplasm at the circumference of the mass is more or less modified, condensed, so that the appearance of a limiting membrane is produced, or **cell-wall.**

A cell then is a mass of nucleated protoplasm, the nucleus may show a nucleolus, and the cell may be limited by a cell-wall. The only essential thing, however, is the living ever-changing protoplasm, and one must ever bear in mind the double process that, while it lives, goes on within the protoplasm, the process of building up lifeless stuff into living stuff, and the process of breaking down by which waste is produced.

Moreover, the amœba we have spoken of multiplies by division, each half thus formed going free as an independent organism, in due time also dividing into two independent organisms. If the animal body be studied in its development, it is found to originate from a single mass of nucleated protoplasm, a single cell, the ovum or egg (fig. 2) showing both nucleus and nucleolus. From this original cell two are formed by division, then four, and so on till a little mass of cells is produced, and from these by further growth and development the animal body with all its various tissues is evolved. This view of the development of living structures was first put forth by two Germans, Schleiden and Schwann, in 1838, and was termed the cell-theory.

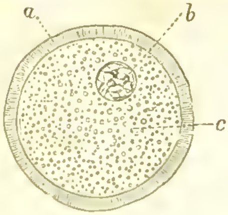

Fig. 2.—Diagrammatic Representation of Ovum. *a*, Zona pellucida, or limiting membrane; *b*, nucleus with nucleoli; *c*, protoplasm of cell with numerous granules and fatty globules. [From Klein.]

Many fully formed tissues consist chiefly of cells, notably the liver (see p. 107). In many others the cells have been modified to form fibres, such as tendon, muscle, nerve, &c. In the blood are found bodies, the white blood corpuscles, exhibiting all the characters of the amœba (fig. 1).

Even such hard and dense structures as bone, gristle, and tooth are formed originally from and by the agency of cells.

The cell is therefore the histological unit of the body. By association, combination, and modification of cells, the body is built up. It may also safely be asserted that if the true character of the changes going on in living protoplasm, the building up and the breaking down process, were accurately understood, the secret of life would be laid bare.

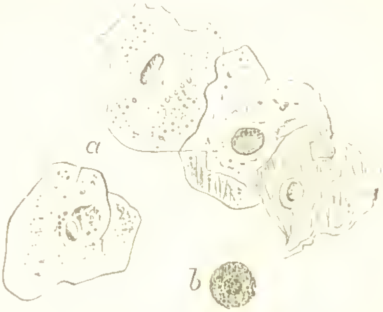

Fig. 3.—*b*, Globular Cell from Salivary Gland, with *a*, Squamous Cells from the Mouth.

Cells vary in size, some being only $\frac{1}{3500}$th of an inch or less in diameter, whilst the largest, the *ovum*, is only from $\frac{1}{100}$th to $\frac{1}{120}$th of an inch in breadth. They also vary greatly in form, as may be seen from the accompanying figures.

The typical cell is more or less **globular** in form, and such are found in glands. A drop of saliva from the mouth will usually exhibit, besides large flat cells, globular cells from the salivary gland. The globular may be regarded as the original shape of cells, other shapes being the result of pressure or similar modifying influences.

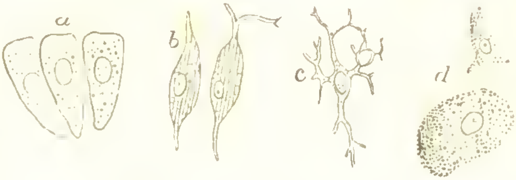

Fig 4.—Various forms of Cells.

a, Columnar cells found lining various parts of the bowel (called *columnar epithelium*); *b*, cells of a fusiform or spindle shape found in the loose tissue under the skin and in other parts (called *connective tissue cells*); *c*, cell having many processes or projections—such are found in connective tissue, may contain pigment; *d*, primitive cells composed of protoplasm with nucleus, and having no cell-wall. All are represented about 400 times their real size.

There are also **columnar cells**, in which the cells are closely ranged side by side (fig. 4, *a*).

Another form is called **ciliated columnar**, in which the columnar cells have delicate prolongations—cilia—from the free surface (fig. 5). These cilia are, when the cell is living, in constant movement, and when observed under the microscope, present the appearance of the passage of a wave, as is seen when the wind blows over a corn-field.

There are cells of **spindle** shape, cells with numerous branching processes, **branched** or **stellate** cells, cells flattened into a pavement form, **squamous** or **pavement** cells (fig. 6), **polyhedral** cells, and so on.

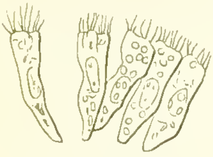

Fig. 5.—Cells of Ciliated Epithelium.

Besides being thus classified according to *shape*, cells may be designated according to *contents*. Thus **fat** cells and **pigment** cells are spoken of, the former being filled with oil, so that it appears as a mere sac of oil, the latter being loaded with dark-coloured granules.

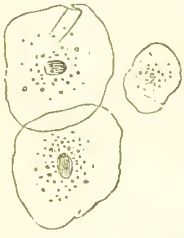

Fig. 6.—Flattened scale-like Cells of *squamous epithelium* from the lining membrane of the human mouth.

Moreover, cells may be described according to their function, or situation, or tissue in which they are found, as epithelial cells, blood cells, gland cells, nerve cells, connective tissue cells.

The **functions** of cells have been already partly indicated. They manifest vitality in various ways:—(1) absorption of matter; (2) transformation of the same either into protoplasm or some material formed by the cell, such as fat or pigment (colouring matter); (3) separation of waste matters of no further use to the cell (excretion); (4) growth or increase in size and development of parts by taking up new matter; (5) development of new cells or descendants which succeed the old ones; and (6) special properties, such as that of changing their form or contracting, or that of nervous activity, as shown by the cells of the nervous system. Each cell has a life of its own. Some live for from 12 to 24 hours, as is likely the case with many of the cells lining the alimentary canal, others may live for many years, as in cartilage or gristle and bone. In glands they are constantly engaged in separating various matters from the blood and elaborating or altering these so as to form new substances.

Thus the cells of the liver form bile, those of the kidney separate certain substances from the blood which are cast away in the urine, whilst those of the salivary glands, and of the glands of the stomach and pancreas, form the juices by which food is digested.

One of the most important views held by modern physiologists is, that the life of the body is the sum of the lives of the individual cells composing it. The body, however diverse its various tissues may appear to be, is built up of myriads of little cells and of tissues made by these, each performing its own function, and yet all acting, in a state of health, for the common good. All our activities depend on actions taking place in cells and in the tissues, and further, all the phenomena of disease are equally dependent on changes in cells.

THE SIMPLE TISSUES.

Epithelium.—Cells are associated and combined in various ways to form simple tissues. Such a simple tissue is called an **epithelium**, and the cells are called **epithelial cells.** The cells are united together by a very small amount of a cement substance which belongs to the proteid class of bodies. The cells forming an epithelium may be globular, squamous, columnar, or ciliated, and so squamous epithelium, columnar epithelium, ciliated columnar epithelium, and so on, are spoken of. Moreover, the cells forming an epithelium may be in a single layer only, or may be several layers deep. In the former case, the epithelium is said to be **simple,** in the latter case **stratified.** It is, then, easy to understand what is meant by **simple squamous epithelium,** and what by **simple columnar epithelium,** and what by **simple columnar ciliated epithelium.** In each case what is meant is a tissue formed of a single layer of cells, but in the

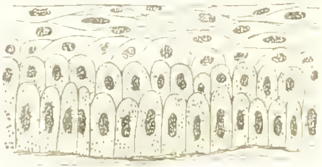
Fig. 7.—Stratified Squamous Epithelium (Klein).

first the cells are squamous, in the second columnar, and in the third ciliated columnar. Then there is **stratified squamous, stratified columnar,** and **stratified columnar ciliated** epithelium. In the case of stratified epithelia it is the character of the uppermost layer of cells that gives the designation. So that of the three last phrases, the first means a tissue formed of several layers of cells of which the uppermost is squamous, the second signifies a similar structure the uppermost layer being columnar, and in the third case the top layer is columnar and ciliated. Now such epithelia are found on the whole surface of the skin, lining the mouth, throat, and whole length of the alimentary canal, and all canals communicating with it, lining the air-passages and recesses of the lungs, the nostrils, canal of the ear, surface of eyelids and eyeballs, lining the tubes and recesses of glands, lining all the closed cavities and tubes of the body, &c., and epithelial structures form the essential parts of the terminal organs of the senses.

Functions of Epithelium.—Such structures may be divided, as regards their function, into two main divisions. One set of them are obviously chiefly protective in character. The layers of epithelium which together form the epidermis or superficial layer of the skin has little beyond such an office to discharge. So is it with the cells covering the mucous membrane of the mouth, and those lining the inner surface of the eyelids and front of the eyeball, of which fig. 7 is a representation. A similar duty belongs to the epithelium lining the air-passages and air-cells of the lungs. Epithelia which discharge so inactive a function are commonly formed of squamous or short columnar cells, and if the situation they protect be much exposed, they are generally stratified. The second great division of epithelia consists of those whose cells are formed of highly active protoplasm, and are busily engaged in some sort of secretion. Such are the cells of glands—the cells of the salivary glands, which secrete the saliva, of the gastric glands, which secrete gastric juice, of the intestinal glands, the cells of the liver, the cells lining the tubules of the kidney, the sweat glands, and so on. Such active epithelial structures are usually formed of a single layer of cells, which are more or less globular in form or long columnar. The whole length of the alimentary canal from the stomach to near the lower termination is lined by a single layer of columnar cells. Many of these cells singly perform the function of a gland. The protoplasm of the cell constructs mucin, with which, by and by, the cell becomes filled to bursting, assuming then the form of a goblet—the **goblet** or **chalice cell.** When the mucus plug is discharged from the cell, the latter resumes its normal columnar form. Similar cells are found in the windpipe.

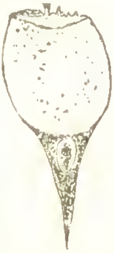
Fig. 8.—Goblet Cell.

Of ciliated epithelium it is necessary to say a further word. The cilia are delicate prolongations of the protoplasm of the cell. They execute a rapid whip-like lashing movement as often as ten or more times a second, and the movement may be quickened or slowed by favourable or unfavourable circumstances. Ciliary movement is readily studied by snipping a small piece out of the gill of the common mussel, and placing it on a slide and examining it under a microscope. Heat quickens the movement, but if the heat be excessive the motion is arrested by coagulation of the protoplasm. Cold slows, and if severe enough stops it, but with the restoration of warmth it is restored. The vapour of chloroform arrests it, but after removal of the vapour the movement is resumed. Carbonic acid gas is unfavourable and oxygen favourable to its continuance. In short, the indications yielded by the movement are highly useful in the determination of the effects of various agents on protoplasmic activity. Now in the case of a ciliated epithelium, all the cilia move in the same direction. In the case of the respiratory passages, this serves to sweep mucus up the passages; and in other canals a similar valuable office is filled by the ciliated epithelium.

THE CONNECTIVE TISSUES.

Under this term are grouped certain tissues, which to all outward appearance vary greatly from one another, for example fatty tissue and bone, but which, nevertheless, are properly grouped together, since (1) they are all produced in the developing body from the same parts, (2) they all fulfil the same function, they act as packing or supporting structures, (3) under certain circumstances one may be substituted for the other, (4) and in certain situations one merges into the other. The following is a list of such tissues:—

I. **Connective Tissues Proper:**
   1. **White Fibrous** Tissue.
   2. **Yellow Elastic** Tissue.
   3. **Adipose** or **Fatty** Tissue.
   4. **Areolar** or **Cellular** Tissue. 6
   5. **Adenoid**, **Retiform**, or **Lymphatic** Tissue.
   6. **Mucous** Tissue.

II. **Cartilage** (commonly called Gristle).
   1. **Hyaline Cartilage.**
   2. **White Fibro-Cartilage.** 3
   3. **Yellow Fibro-Cartilage.**

(1) III. **Bone** and **Dentine** of Tooth.

All of these tissues consist of three elements, the proportion of which varies in each tissue, namely, (1) a ground-substance or matrix, (2) cells, and (3) fibres.

The ground-substance is best seen in hyaline cartilage, where it is transparent and glassy-looking, but in the connective tissues proper it is in small amount and is obscured by the mass of fibres. In bone (and in tooth) this ground-substance is infiltrated with salts which give the bone its hardness, and make it so seemingly different from the other tissues. The cells are, in the connective tissues proper, called **connective tissue corpuscles**, in cartilage they are called **cartilage cells**, and in bone **bone corpuscles**. The fibres are of two kinds, one exceedingly fine, transparent, and running a wavy course in bundles, the fibres of white fibrous tissue; and the other coarse, yellowish, and elastic, the fibres of yellow elastic tissue. These it will be best first to describe.

White Fibrous Tissue (fig. 9, 1) consists of bundles of very delicate fibrils. In each bundle the fibrils run a more or less parallel course, though wavy. The bundles are bound together by a small amount of cement substance. Associated with them are the connective tissue corpuscles, irregular masses of nucleated protoplasm, often branching, but determined as to shape by the pressure exerted on them by the bundles. They lie on the bundles, in minute passages between them, when these run parallel as in tendon, or in spaces inclosed by the bundles when these cross to form a felt-work as in the loose tissue under the skin, subcutaneous tissue. On boiling, white fibrous tissue yields gelatin, and on the addition of a dilute acid the bundles swell up and become cloudy and gelatinous.

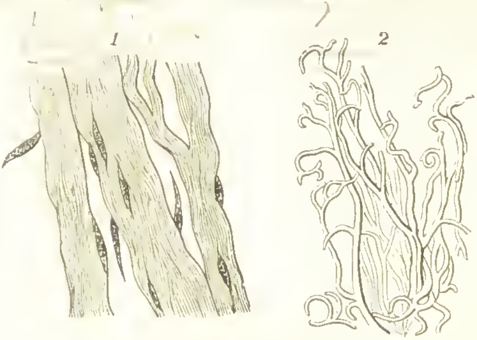

Fig. 9.—Fibres of (1) White Fibrous, and (2) Yellow Elastic Tissue.

Now this tissue is found forming part of various structures, skin, tendon, membranes, loose tissue between and over muscle, beneath skin, &c., and in these different situations the bundles are variously disposed, parallel in tendon, crossing and recrossing in skin and intermuscular tissue, &c.

Yellow Elastic Tissue (fig. 9, 2) also consists of fibres, which, however, are much stronger and coarser than those of white fibrous tissue. They are yellowish, and tend to split and curl up at the ends. They possess a high degree of elasticity. It is the presence of these fibres that confers elasticity on the skin, and on the coats of blood-vessels. This tissue is the main component of the ligamentum nuchæ, the broad ligament in the back of the neck of large quadrupeds, for the support of the heavy head. It does not yield gelatin on boiling, acetic acid has no effect on the fibres, and cells are few if any.

Cellular or Areolar Tissue is made up of bundles of white fibrous tissue interlacing and crossing one another to form a mesh-work. Numerous elastic fibres are present, conferring elasticity. The two kinds of fibres are easily distinguished by adding dilute acetic acid, when the white fibres swell up, become transparent, and the unaffected yellow fibres are revealed. The interlacing bundles inclose little spaces or areolæ, hence the term areolar or cellular. Attached to the bundles or lying in the spaces are connective tissue corpuscles and other cells, identical with white blood corpuscles, which have probably found their way by amœboid movement (p. 27) from the blood-vessels abounding in the tissue. It is a tissue found in large quantity under the skin, covering the muscles, the blood-vessels, and nerves, and in various parts forming a kind of protective covering for delicate and important organs. It is because of its general distribution, and because of its binding various structures together, that it is called connective. The little spaces do not actually exist in health, but are filled up with fluid that has oozed out of the blood-vessels.

Adipose Tissue or Fat contains fibres of white fibrous tissue, forming a mesh-work in which fat cells are embedded. These fat cells are round or oval, and consist of ordinary connective tissue cells, in which oil drops have accumulated till the cells resemble little envelopes or sacs filled with oil. The oil may be removed and used up in the body, and then the cells are once more ordinary connective tissue cells. Adipose tissue forms a considerable layer beneath the skin, covers various internal organs, and is found in the marrow of bones and elsewhere. It is protective, in the sense of acting as a packing agent between organs; and it prevents the heat being carried off too quickly from the body, as it is a bad conductor.

Adenoid Tissue is described on p. 125.

Mucous Tissue is found chiefly in the early stages of development, subsequently undergoing change to ordinary connective tissue. It consists of numerous large branching connective tissue cells, lying in a clear homogeneous semi-fluid mucous substance.

In general the connective tissues proper act as packing, binding, and supporting structures. Where white fibrous tissue chiefly abounds, structures are held together, and there is flexibility but little or no distensibility. Where elastic tissue is prominent there is not only support but elasticity. The structure yields to stretching, and returns to its original position on the removal of the stretching force.

Cartilage or Gristle.—Hyaline cartilage consists of a ground-substance of a fine ground-glass appearance, containing cells, which have a nucleus and nucleolus, and lie in spaces in the ground-substance inclosed by a capsule. One cell may fill one space, but oftener two, three, four or more cells are present, which have obviously originated by division from one original cell (fig. 10).

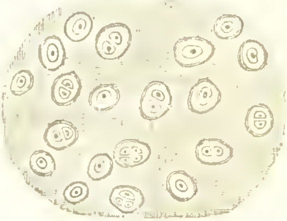
Fig. 10.—Hyaline Cartilage, as seen magnified.

In white fibro-cartilage the ground-substance is everywhere pervaded, and almost replaced, by white fibrous tissue, disposed in layers of bundles, the encapsuled cartilage cells lying between the bundles.

In yellow fibro-cartilage yellow elastic fibres form a basket-work, the cartilage cells occupying the meshes.

The first variety is found coating the opposing ends of bones, entering into the formation of a joint (articular cartilage), forming the portions of the ribs that become attached to the breast-bone (**costal** cartilage), and it is this kind of cartilage that occupies the place of bone in early life, being afterwards replaced by bone. White fibro-cartilage is found in the discs between the vertebræ of the spinal column; and the third variety forms the main portion of the lid of the windpipe—the epiglottis (p. 178), and of other cartilages of the voice-box or larynx (p. 178). Cartilage is tough but highly elastic. It thus tends to resist change of form, while yielding to sufficient force and returning afterwards to its original form. Disposed between bones it acts as a buffer, while permitting a certain amount of flexibility.

It will be convenient to discuss bone in a separate chapter. For dentine see p. 97.

CHAPTER III.—BONE: ITS COMPOSITION AND MINUTE STRUCTURE; DESCRIPTION OF THE BONES OF THE SKELETON: THE JOINTS.

BONE.

Bones consist of an earthy or mineral part and an animal part. If a bone, say a rib of an ox or sheep, be steeped for several weeks in dilute hydrochloric acid, the mineral matter is dissolved out by the acid, and there remains the animal matter. It retains perfectly the outward form of the bone. It is no longer hard, however, but soft and flexible. On the other hand, if a bone, say the knuckle from a joint, be put into a clear fire, the animal matter is slowly burned away, and only the mineral remains. The bone by the burning first becomes black, and then, as the last trace of animal matter disappears, it becomes pure white. The earthy matter also retains perfectly the shape of the bone, but is very brittle, and liable, at the slightest touch, to crumble to dust. The earthy matter forms less than 70 of every 100 parts of the bone, and the animal or organic matter over 30 of every 100, less than one-third.[1] The animal matter is ossein and on boiling yields gelatin; and the earthy con-

---

[1] Chemical composition of bone:—

Organic Material, ...		33 per cent.
Inorganic or Earthy Material—		
Phosphate of Lime, ..	57 per cent, ..	67 .. ..
Carbonate of Lime, ..	7 ,, ...	
Phosphate of Magnesium,	1 to 2 ,, ,, .	
Fluoride of Lime, ...	1	
Total,		100

sists of phosphate and carbonate of lime, phosphate of magnesia, and chloride of sodium (common salt). In childhood bones contain a larger percentage of animal matter, therefore they are flexible and more liable to bend than to break; while, in old age, they contain a greater percentage of mineral matter, and therefore are more brittle and easily broken.

Usually when a bone is sawn through it is found to have a shell of hard, compact bone outside, and inside the plates of bone are less closely packed, spaces being left between, giving a spongy look. This spongy bone is called **cancellated**. Fig. 11 shows this very well. A long bone has in its centre a cavity called the **medullary canal**, filled with a soft, yellowish, pulpy substance, consisting largely of fat (96 per cent) and called the **medulla or marrow**.

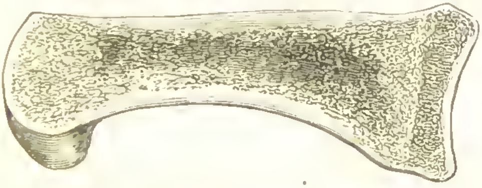

Fig. 11.—Showing dense bone outside, spongy bone within.

Bones are usually classified as *Long*, or *Cylindrical*, such as the long bones of the arm or leg, *Short*, or *Irregular*, such as the small bones of the wrist and sole of the foot, and *Flat*, or *Tabular*, such as the bones of the skull.

Bone is completely covered outside by a dense fibrous coating called the **periosteum**, which is richly supplied with blood, and plays a chief part in the growth of bone. The cavity in a bone is also lined with a similar membrane called **endosteum**, also rich in blood-vessels.

The bone itself seems so dry and hard as to have no moisture within it, nor any blood supply; but this is not the case, for blood-vessels pass into it from the periosteum through minute openings, and most long bones have besides a special artery (**nutrient artery**) entering them to carry a due supply of nourishment. If a very thin slice be taken from across a bone and examined under a microscope, magnifying about 300 diameters, an appearance is presented like that shown in fig. 12, B. Little openings (*a*, *b*) are observed, and round them are ranged rings of bone, with little black bodies in them, from which fine dark lines branch out. These openings are canals cut across, called **Haversian canals**, after Havers, who first described them; the black bodies are spaces, called **lacunæ** (little lakes), in the bony plates, while the fine dark lines are very narrow canals which connect the lacunæ with one another and with the Haversian canals. The narrow channels are called **canaliculi**. A, of the same figure, shows a section taken lengthways, by which the

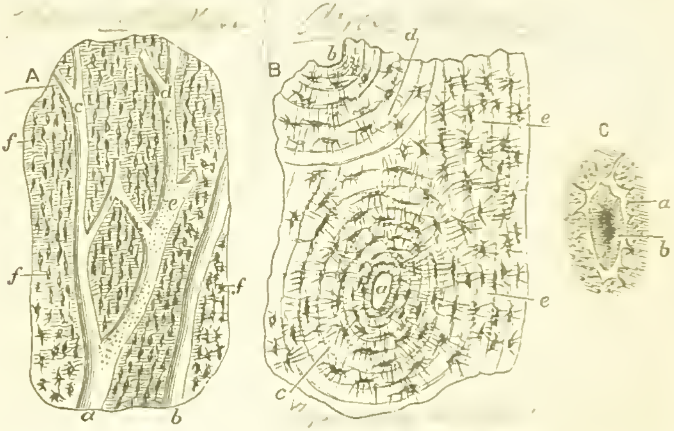

Fig. 12.—Microscopical appearance, A, of longitudinal section of bone, and B, of transverse section. C, A bone cell, highly magnified, lying in lacuna.

Haversian canals (*a*, *b*) have been opened up, not cut across, and are seen branching and communicating with one another. Now, in these Haversian canals, blood-vessels run; the lacunæ contain bone cells, which are to bone what the connective tissue corpuscles are to that tissue. The rings of bone round the Haversian canals are lamellæ, or layers, of dense fibrous tissue, the ground substance of which has become hard by deposition of lime salts, and the bone cells lie in spaces—the lacunæ, between the fibrous lamellæ. So that if the salts are removed, the resemblance between bone and connective tissue becomes apparent. Along the canaliculi run, at least for some distance, branches from the cells. Thus bones have not only a large blood supply obtained from the nutrient artery, and from the periosteum covering the outer, and the endosteum lining the inner, surface, but contain innumerable little cells of living material, which are capable of maintaining a constant network of nourishing channels through the whole bone.

Early in the life of the child, months before it is born, there are no true bones in its body, their place being occupied by **cartilage** (gristle). The masses of cartilage have, however, the shape of bone, and it is within them the bones are developed. Take such a one as the thigh-bone; it is found that shortly before birth only the shaft has become true bone, the two extremities being still made of cartilage (fig. 13, A). Just at birth a small deposit of earthy matter is found in the lower end (B, 2), which goes on extending. At one year of age a second deposit is seen in the upper end (C, 3). These little deposits from which the bone forms, are called **centres of ossification**. The bone formation goes on from these centres till the ends are quite bony, and cartilage exists only at the place of junction between the shaft and the two extremities. The two ends are called **epiphyses**, and may readily be separated at this stage from the shaft. This is an accident which sometimes happens to children, and since it is at this point of junction that the principal growth in the length of the bone occurs, such an accident may seriously interfere with the growth. The union between shaft and epiphyses does not take place till maturity, when further growth in the long direction ceases. Bones increase in thickness by growth from the inner surface of the periosteum. If, by accident

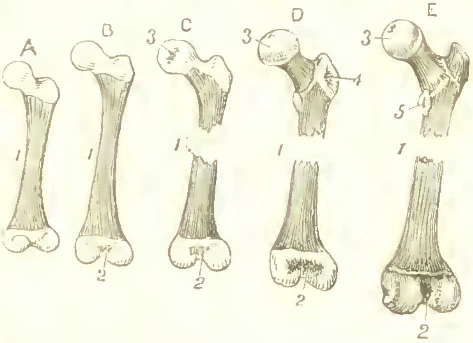

Fig. 13.—Centres of Ossification of the Thigh-bone.

or disease, the periosteum be stripped off, no increase in thickness can take place, and the surface of the bone, deprived of its nourishment, will die; and, for a like reason, destruction of the inner lining membrane would impair the vitality of the inner surface.

The Skeleton.

The **skeleton** (Plate I.) forms the hard framework of the body, and is composed of bones united with one another by joints of various forms, in many cases plates or pads of gristle being interposed between the opposing bones to permit of movement, the union being further strengthened by strong and dense fibrous bands, which bind the one bone to the other.

The skeleton is divided into **Head, Trunk,** and **Limbs,** and is made up of more than 200 separate bones in all.

The **Head** includes the part inclosing the brain, called **cranium,** and the **face,** the former containing eight bones, and the latter fourteen.

The eight bones of the cranium are the **frontal,** two **parietal,** the **occipital,** two **temporal,** the **sphenoid,** and the **ethmoid.**

The **frontal** (figs. 14 and 15, A) forms the forehead and part of the vault of the skull, as well as part of the roof of the sockets for the eye-balls. In children the frontal bone is in two parts, with a division passing down the middle. The **parietal** (B) bones form the great portion of the roof, and meet the **occipital** behind, which completes the roof, and is continued onwards to form a large part of the floor or base of the cranial cavity. The part of the occipital forming the floor is pierced by a large opening called

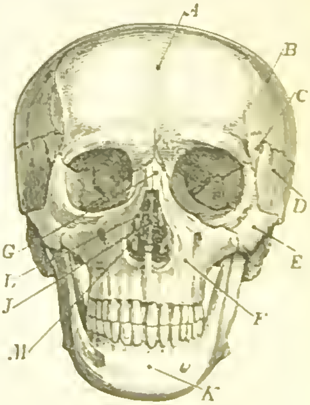

Fig. 14.—The Head, viewed from before.

the **foramen magnum** (fig. 16), through which the spinal cord passes to reach the brain. In fig. 15 O is pointing to the extreme side limit of the occipital bone. The sides of the cavity are closed in by the **temporal bones** (D), one on each side. These contain the organ of hearing. In the figure, D′ indicates a downward projection of the temporal bone, which is situated just behind the ear. It is called the **mastoid process.** The gap in the floor of the cranial cavity left by the occipital is filled up by the **sphenoid** (fig. 16), which thus stretches between the occipital behind it and the plates of the frontal occupying the roof of the eye-sockets in front of it. Part of the wing of the sphenoid is seen in figs. 14 and 15, and is marked C; but the main portion is at the base of the skull, and within, and is therefore seen in fig. 16. The **ethmoid** is a very spongy bone, is not visible from the outside, and fills up the interval between the orbits. It forms the roof of the cavity of the nose, and is pierced by small openings for the passage of the nerves of smell. In fig. 15, *e* shows the side of the ethmoid forming part of the inner wall of the orbit; the other side of the bone is in a similar position on the inner wall of the other orbit.

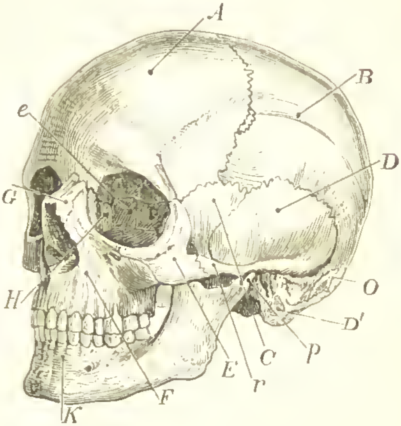

Fig. 15.—The Head, viewed from the side.

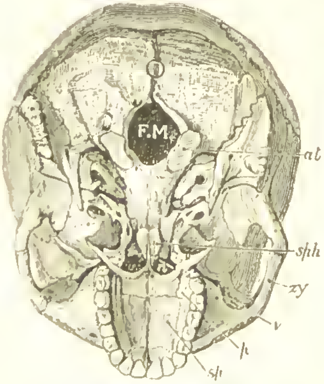

Fig. 16.—The Base of the Skull.

The fourteen bones of the face are—two upper jaw-bones (**superior maxillary**), two **malar** or cheek bones, two **nasal**, two **palate**, two **lacrymal**, two **inferior turbinated** bones, and the **vomer** or ploughshare in the nasal cavity, and the lower jaw-bone (**inferior maxillary**). The **upper jaw-bones** (F) carry all the upper teeth, and form part of the floor of the orbit, the rest of which is completed by the **cheek-bones** (E), which also send an arch backwards to join the temporal bone. These arches (**zygomatic arches** *r*, fig. 15) are the prominent ridges which run out from below the outer angle of the eye to the front of the ear. The **nasal bones** (G) form the bridge of the nose, and at their upper end they come into contact with the **lacrymals** (H, fig. 15), placed in the inner angle of the orbit, and grooved for a duct, along which the tears pass from the eye to the nose. The cavity of the nose is divided into two by the **vomer** (J, fig. 14), so called from its resemblance to a ploughshare, which forms a middle wall of partition between the two nostrils, while the **inferior turbinated** are scroll-like bones which project from the wall in the inside of the cavities (M and L, fig. 14). The **palate bones** are behind those of the upper jaw, and with them form the bony part of the roof of the mouth. The **lower jaw-bone** (K) is the largest of the face bones, and carries all the lower teeth. It is the only bone in the head which is movable, a hinge joint being formed between its strong processes, projecting upwards (*p*, fig. 15), and a hollow in the temporal bone under the ends of the zygomatic arch. All the other bones of the head are immovably connected with one another, one bone presenting a ragged edge, like badly-formed teeth of a saw, the teeth fitting into corresponding notches in the edge of the other bone. These irregular lines of union are called **sutures**.

The **Trunk** consists of the backbone or **vertebral column**, on the top of which the head is supported, and the chest or **thorax**.

The **Vertebral Column** is composed originally of 32 separate pieces, each piece being called a **vertebra**. In the adult state the separate pieces number only 26, several having become fused together. The separate pieces are arranged one on the top of the other, cushions of gristle being interposed between each (fig. 17, *g*, *g*), which also help to unite them, while the union is completed by partially movable joints and by strong fibrous bands called ligaments. The column so arranged presents two forward curves, the first (*a*) in the neck, the second (*b*) at the lower part of the back, and there are two corresponding backward curves. The first seven vertebræ (1 to 7) occupy the region of the neck, and are, therefore, called **cervical** (Latin, *cervix* = the neck); twelve (from 7 to 19) are the supports from which spring the ribs, and constitute the main portion of the back, being called accordingly **dorsal**; the next five (19 to 24) are called **lumbar**, in the region called the "small of the back." Following these there come five bones, separate in early life, but united in the adult into one piece called the **sacrum**, which forms with the haunch bones on each side a large cavity—the **pelvis**. Attached to the end of the sacrum is a small pointed bony mass, containing four vertebræ, originally separate and of a rudimentary kind, which corresponds with the bony part of the tail in other animals, and is called the **coccyx**.

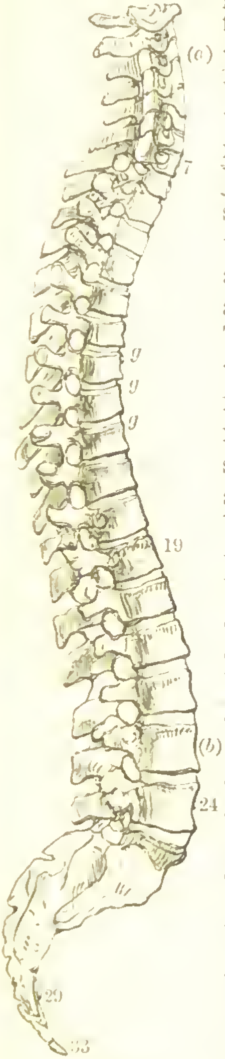

Fig. 17.—The Vertebral Column.

Each vertebra consists of a *body* (fig. 18, *a*) from which two *arches* pass backwards (*c*, *c*), which meet in the middle line (*b*) and are prolonged into a spine—the **spinous process** (*d*). The arches inclose a *ring* (*h*). Projecting upwards and downwards from the sides of the ring are processes—two above by which the vertebra is united to the one above it, and two below for union with the one below it. These are called articulating processes (*g*, fig. 18). Just about the position of these, there pass transversely outwards other two processes, one on each side, called the transverse processes (*f*). Now, when the vertebræ are in position the spinous processes are in line. They project backwards—the bodies being in front (see fig. 17), and give the irregular feeling that is experienced when one passes the hand down the centre of a person's back. At the same time the rings are all one above the other, and so form a canal (*the spinal canal*) in which the spinal cord lies, and by the bony walls of which it is protected. The vertebræ differ in form according as they belong to the cervical, dorsal, or lumbar region. The cervical vertebræ (fig. 19) have a canal (*f*) in the transverse process for the passage of an artery, and their spinous processes (*d*) are split at the extremity. The bodies of the lumbar vertebræ are more massive than those of the dorsal. Their transverse and articulating processes are more marked (see fig. 20, references the same as in fig. 18), and their spinous processes are hatchet-shaped

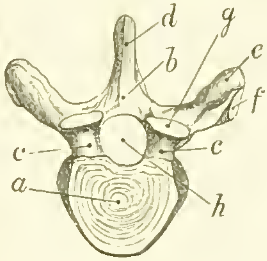

Fig. 18.—A Dorsal Vertebra.

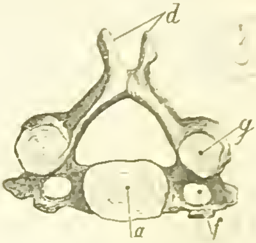

Fig. 19.—A Cervical Vertebra.

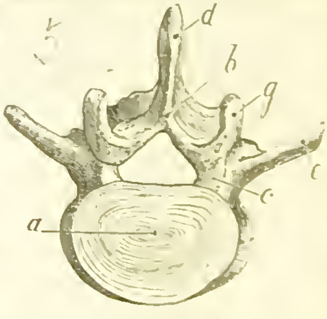

Fig. 20.—A Lumbar Vertebra.

and point straight backwards, while the spinous processes of the dorsal vertebræ overlap one another, and the transverse processes have little polished surfaces for uniting with the ribs (fig. 18, *e*) The bodies of the vertebræ are of a different shape in the three kinds, as may be seen from the figures. The two uppermost vertebræ are peculiar. The first is called the **atlas** (fig. 21) because it bears the head. It has very large surfaces (*g*) for a joint between it and processes of the occipital bone, and it is owing to this joint that the nodding movement of the head is possible. This vertebra has no body, but, instead, a small ring, separated from the large one (*l*) by a strong fibrous band which passes across between the two (see arrow lines in fig. 21, *k*). The second vertebra is called the **axis** (fig. 22), because its union with the first is such as to permit a rotary movement between them, by which the head is turned to one side or another. This is effected by means of a process called the **odontoid** or tooth-like process, fig. 22, *c*, *b*, *e*, which springs upwards from the body of the axis and fits into the smaller of the two rings of the atlas. The odontoid process is retained in this position by means of a joint between the surface *e* (fig. 21) of the axis and the surface *d* (fig. 22) of the process, as well as by strong fibrous bands, which also prevent it rotating too far, and particularly by the ligament already mentioned as passing across between the two rings of the atlas. This ligament, in the living state, intervenes between the process in front of it and the spinal marrow behind it, and if it were to break,

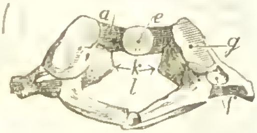

Fig. 21.—The Atlas Vertebra.[1]

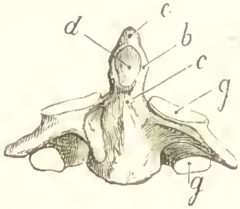

Fig. 22.—The Axis Vertebra.

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[1] The position of this figure is different from that of the others. It is the back part that is nearest the person looking at it. In the other figures it is the body or front part that is nearest.

the process would press backwards, destroy the spinal cord at this point, and so cause instant death. This occurs when the neck is broken.

The **Chest or Thorax** consists of the twelve dorsal vertebræ behind, of twenty-four ribs, twelve on each side, which spring from the vertebræ and arch forwards, and of the breast-bone or **sternum** (*o*, *p*, *q*, fig. 23), to which, by means of cartilages, most of the ribs are united in front. All the twelve ribs on each side (1 to 12 in figure) are not connected with the breast-bone. The first seven have each a separate piece of cartilage (*c*, *c*) uniting them, and are therefore called "**true ribs**;" the three next in succession are united by the same piece of cartilage, while the last two are quite unconnected with the sternum, and terminate in the muscular wall of the belly. The last five are termed "**false ribs**," the last two (*f*, *f*) being also called "**floating ribs**."

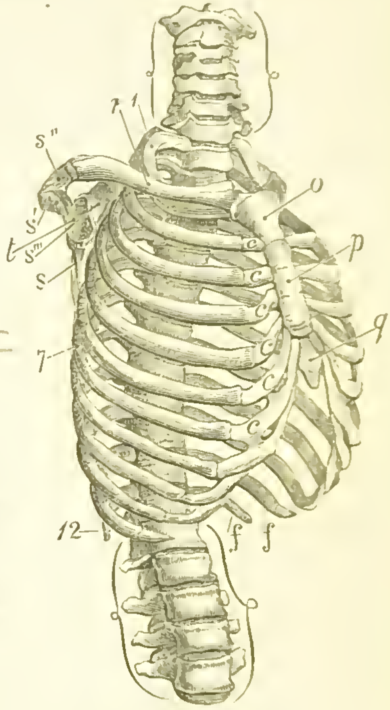

Fig. 23:—The Thorax.

The upper vertebræ inclosed in brackets are cervical, the lower lumbar.

The attachment of the ribs to the vertebræ is by joints which allow of considerable movement, so that the ribs can be elevated or depressed, and thus the cavity which they inclose may be increased or diminished in size. The cartilages confer elasticity on the bony walls of the chest: but in advanced life much of this elasticity is lost by the cartilages becoming brittle owing to a deposit of lime in them, and consequently the chest becomes less capable of movement.

The **Upper Extremity** is connected with the thorax by means of two bones which together receive the name of the shoulder girdle. They are the collar-bone or **clavicle** (*r*, fig. 23), and the shoulder-blade or **scapula** (*s*). The **collar-bone** stretches from the top of the breast-bone (*o*, *p*, *q*) outwards, and forms the prominent point of the shoulder. The **scapula** lies on the back of the thorax, where it is freely movable, and is attached to the outer end of the clavicle by strong fibrous bands. It has a strongly developed spine (s') for the attachment of muscles, and two processes (*coracoid* s''' and *acromion* s'', the latter a prolongation of the spine) by which its attachment to the clavicle is effected. At one of its angles it has a polished hollow (*t*) lined with cartilage, into which the head of the arm-bone or **humerus** (fig. 24) fits, thus forming the shoulder joint. The lower end of the humerus is broadened out by a projection on both the outer and inner sides, the outer and inner **condyles**, and has a pulley-like surface (*b*) for articulating with the forearm to form the elbow joint. The **forearm** consists of two bones, **ulna** and **radius**. The **ulna** (fig. 25, 1) is the inner of the two, is large at the upper end, where it has two projections, one, *the coronoid* process (*b*), in front, and the other, the *olecranon* process (*a*), behind. Between these two is a deep groove (*c*) into which the smooth pulley-like surface of the humerus is received, forming a hinge joint. The olecranon behind forms the sharp prominence of the elbow. The lower end of the ulna is slender. The **radius** (fig. 25, 2) is

Fig. 24.—The Humerus.

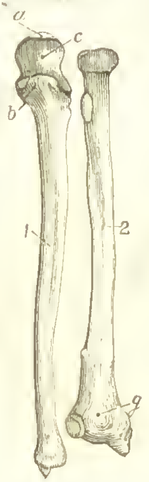

Fig. 25.—The Ulna and Radius.

The bones are shown displaced from one another in the figure. The radius (2) is above its proper position. Its head should move on the side of the ulna below the level of the hollow (c).

the outer of the two bones, is small at the upper end, where it is connected with the ulna, so as to permit its head to have a rotary movement, and is large and expanded at the lower end (*g*), where it forms part of the wrist joint. The arrangement of these joints is such that the radius can roll, as it were, half-way over the ulna. It carries the hand with it, which is thus turned palm downwards—in the act of what is called **pronation**; when the radius is rolled back again the hand is turned palm upwards, that is, the back of the hand is now downwards—**supination.**

The **wrist or carpus** (fig. 26) is made up of two rows of small bones, four in each row. Beginning from the thumb side these bones are named as follows: **scaphoid** (1), **semilunar** (2), **cuneiform** (3), and **pisiform** (4), in the first row; **trapezium** (5), **trapezoid** (6), **os magnum** (7), and **unciform** (8), in the second row. These small bones are allowed a slight amount of movement on one another by means of joints. The **palm** of the hand contains five shafted bones called **metacarpal** bones (*m*), which means coming after the carpus or wrist. These metacarpal bones support the **phalanges** (*p*) or bones of the finger. There are three phalanges in each finger, diminishing in size towards the point. The thumb has only two phalanges (fig. 26, *p′*).

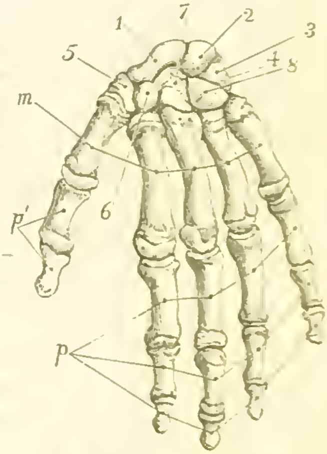

Fig. 26.—The Hand, from behind.

A dotted line leading to 4 shows the position of the pisiform bone, which rests on the cuneiform, and can be seen only from the front.

The **Lower Extremity**, like the upper, is connected to the trunk by means of a girdle called the **pelvis** or **pelvic girdle** (fig. 27). The pelvis is formed behind by the prolongation of the vertebral column, **os sacrum** and **coccyx** (*S* and *C*). Arching forwards from the sides of the sacrum are two large irregularly shaped bones, one on each side. The name given to each of these bones is **innominate bone** or the unnamed bone. In the figure the lines *I* on each side of the vertebral column indicate the place of union with the sacrum. The innominate bones meet in front at the **symphysis pubis** (*sp*), a pad of cartilage intervening. Each innominate bone consists in early life of three pieces, termed **ilium** (A), **ischium** (B), and **pubis** (C). When the pelvis is looked at as a whole a prominent ring can be followed from the sacrum behind round to the symphysis in front, this is called the brim of the pelvis. The inclosed cavity contains the urinary and generative organs and the lower part of the bowel. In the erect position the pelvis forms an angle of 60° with the horizontal, so that the pressure communicated by the vertebral column is thrown, by this inclination, on to the innominate bones. Strong fibrous bands, passing from the sacrum to the part of the innominate bone called the ischium (at the point where the B is placed in the figure), prevent the sacrum from being forced forwards by the pressure. In the pubic portion of the bones is an irregular opening (*o*) through which blood-vessels, nerves, &c., pass outwards. In the innominate bone of each side is a large and deep irregularly formed cavity (*a*), which is lined with cartilage and receives the head of the thigh-bone. It forms a very deep socket; and the thigh-bone has a correspondingly large globular head. This large socket is called the **acetabulum**.

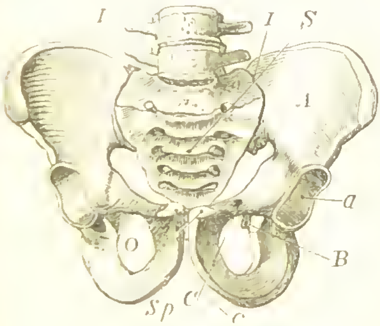

Fig. 27.—The Pelvic Bones.

The **thigh-bone or femur** (fig. 28) is a very large and strong bone, and presents a shaft (A) with a rough ridge on the back for the attachment of muscles. At its upper extremity, besides the globular head (1) already mentioned, it has two rough prominences, one large and external (2), the other small and internal (3). These are called the **large** and **small trochanters**. The former can be felt just beneath the skin on the outer side of the hip-joint. The lower end of the femur is broad and irregularly shaped, and has two enlargements, one to the inner, the other to the outer side, called **condyles**, fitted for forming a hinge joint with the succeeding bone of the leg. The leg has two bones, the inner called **tibia** or shin-bone (fig. 28, 1), the outer called **fibula** or clasp-bone (2). The tibia is much the larger of the two, and above is connected with the thigh-bone (at *b*) to form the knee-joint, the fibula being attached to the outer side of its head. In front of the knee-joint, situated within a tendon, is the knee-cap or **patella** (fig. 28, 3).

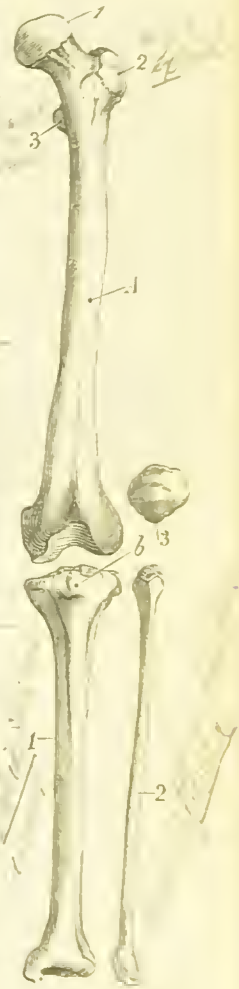

Fig. 28.—The Bones of the Leg, left side.

The lower end of the tibia and of the fibula enter into the formation of the ankle-joint, the weight being conducted to the foot by the tibia. The lower end of the tibia projects on the inside of the joint, and the lower end of the fibula has a similar prominent process on the outside of the joint. These processes are termed **malleoli**.

The **foot** (fig. 29) consists of three parts, like the hand, **tarsus**, **metatarsus**, and **phalanges**. The **tarsus** consists of seven bones, viz.: **os calcis** or heel-bone (1), the **astragalus** (2), resting above the os calcis and supporting the tibia. the **cuboid** (3), in front of the os calcis. the **scaphoid** (4), in front of the astragalus, and in front of the scaphoid are the **internal** (5), **middle** (6), and **external** (7), **cuneiform**. Like the five metacarpal bones forming the palm of the hand, and succeeding the tarsus, are five **metatarsal** bones forming the sole of the foot (*m*). To these succeed the bones of the toes, each toe having three **phalanges** (*p*), except the great toe, which has only two. Here the resemblance to the fingers and thumb is apparent.

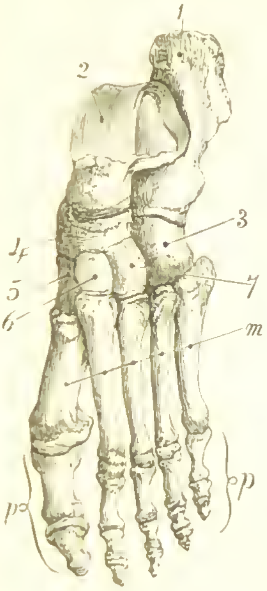

Fig. 29.—The Foot.

Fig. 30 gives a good side view of the foot, showing well the position of the tibia astride of the astragalus, and the great projection behind of the os calcis (C), which affords an extensive surface of attachment for the tendon of the calf of the leg. This figure also shows the peculiar arch of the foot, of which the os calcis and the balls of the toes are the piers, the keystone being the astragalus. It is easily seen how well this arrangement is adapted for supporting the weight of the body.

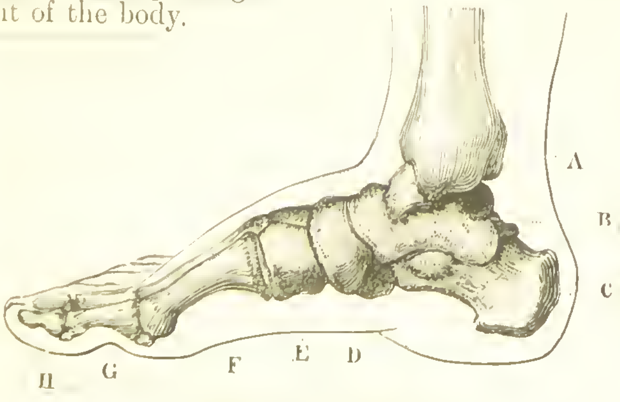

Fig. 30.—The Foot, from the side.

A, Tibia. B, Astragalus. C, Os calcis. D, Scaphoid. E, Internal cuneiform. F, Metatarsal bone of great toe. G, H, Phalanges of great toe.

THE JOINTS.

By **Joint** or **Articulation** is meant the union of two bones by means of structures of a different kind. The structures that enter into the formation of a joint are: (1) **bone**, (2) **cartilage** or gristle, (3) **synovia**, a smooth delicate membrane which lines all parts of the inside of the joint except the opposing surfaces of cartilage, (4) **ligaments**, strong bands to bind the bones together.

(1) **Bone and Cartilage** have already been described (pages 38 and 37).

(2) The **Synovial Membrane** is a very delicate fibrous connective tissue lined on its inner surface by a layer of simple squamous epithelium (p. 31). It is richly supplied with vessels, and from it a fluid, *synovia*, is poured out to moisten the cavity of the joint and so reduce the amount of friction and heat developed by movement.

Synovial membrane is a variety of what are called, in general terms, **serous membranes**. Such membranes are found lining the inner surface of the wall of all cavities of the body shut off from the exterior. Thus the inner surface of the walls of the abdominal cavity is lined with such a membrane. As a rule, also, they line the opposing surfaces of organs lying in the cavity; so that where the organs come into contact with one another the smooth surface of the membrane is interposed between them. If any movement of one organ on the other is permitted the presence of the membrane ensures the gentle gliding character of the movement. If to any organ lying in one of the cavities of the body a certain amount of movement is, in the nature of the case, necessary, such organ is invested with a serous membrane in a double layer to facilitate the movement. Such is the serous membrane of the pericardium of the heart (see p. 150). Again, the lungs move in the chest in the acts of expansion and emptying during breathing. Therefore their surfaces are covered with a serous layer which is reflected on to the inner wall of the chest, so that in the movement one layer glides on the other.

This is the serous membrane of the pleura (see p. 184). Then tendons move in the contraction of muscles, and so they are provided with sheaths of serous membrane. In all such cases there is no actual space between the two layers of the membrane, and the serous fluid—in the case of joints, the synovial fluid—is produced by the cells covering the inner surface in such quantity as only to lubricate the membrane. In disease the fluid may be produced in such quantity as to separate the two layers and produce a space filled with fluid.

(3) **Ligaments** are dense bands of white fibrous tissue, not elastic, which pass from one bone to another, strongly supporting the joint, which sometimes they completely surround.

In a joint, then, there are the ends of two opposed bones, of which the opposing surfaces are coated with cartilage; strong ligaments pass between them to complete and maintain the union; and the inner surface of the joint cavity is lined by a membrane which pours out a fluid to lubricate the joint.

It is, however, only **perfect joints** that are thus fully equipped, and there are joints which want one or other or several of these structures, which are therefore called **incomplete or imperfect joints.**

Imperfect Joints. (1) The bones of the skull are united by their ragged or serrated edges being dovetailed into one another, no structures intervening between the bones. Such joints are called **sutures** and are immovable.

(2) In the union effected between the bodies of the vertebræ there is an example of incomplete joints, which are *partially* movable. Between two opposed bodies of vertebræ there is a cushion of cartilage of the white fibrous kind. The pads are elastic and useful in preventing jars to the vertebral column. Besides, they allow of a considerable amount of movement over all, though very little between any two vertebræ. The union is strengthened by ligaments, but there is no synovial membrane.

Of **Perfect Joints** there are various forms, according to the nature and amount of the movement permitted.

(1) *Ball-and-socket Joints.* In this form one bone has a cup-like depression into which the head of the other fits. This is the kind of joint existing between the head of the arm-bone and the glenoid cavity of the shoulder-blade, and between the head of the thigh-bone and the acetabulum of the innominate bone. In the hip-joint the head of the bone is kept close in the cavity by means of a special ligament within the cavity itself, the **round ligament**, which passes from a depression in the bottom of the acetabulum to the head of the thigh-bone. Ball-and-socket joints permit free motion in almost any direction.

(2) *Hinge Joints.* Here the opposing surfaces of the bones have elevations and depressions which fit into one another and allow of movement only in one direction. The elbow, ankle, and knee joints are examples of this kind.

(3) *Pivot Joints.* The best example of this is the joint between the first and second vertebræ, the pivot being formed by the odontoid process of the axis, and the ring in which it is placed being provided by the atlas vertebra. The kind of movement permitted here is rotary.

(4) *Shifting Joints.* In this last kind the amount of movement is restricted and amounts to only a slight gliding between the ends of the bones. The joints between the bones of the wrist and those between the bones of the ankle are good examples.[1]

Besides the ligaments and muscles a force tending to keep bones in joint is the pressure of the outside air. The hip-joint, for example, is so completely surrounded by ligaments as to be air-tight; and the union is a very strong one. If the ligaments be pierced and air allowed to enter the joint, the union becomes at once much less close and the head of the femur falls away as far as the ligaments will allow it.

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[1] Certain technical terms are applied to the various kinds of joints:—

Synarthrosis is the term applied to the first kind of imperfect joint, the sutures of the skull, for example.

Amphiarthrosis is the partially movable joint seen in the vertebræ.

Diarthrosis applies to the complete joint with its varieties of (1) ball-and-socket, (2) hinge, (3) pivot, and (4) shifting.

Joints allow of various kinds of movements, the chief of which are:—

1. *Angular movement*, as when the bones so move as to form an angle between them in the same line or plane. Angular movements include those of *flexion* and *extension*, as when we bend or straighten the forearm on the arm at the elbow, *adduction*, as when the arm is brought to the side from the extended position, and *abduction*, when it is carried from the side towards the extended position.

2. *Coaptation* is the term applied when one surface glides over the other like a wheel rolling on the ground, so as to bring successive surfaces into contact. This is seen in the movement of the knee-pan on the lower end of the femur.

3. *Circumduction* occurs when the shaft of a long bone describes a cone, the apex of which is in the joint, while the base and sides of the cone are described by the moving part, as exemplified by the swinging of the arm when we attempt to make a circle in the air on one side of the body. The same movement can be described by the leg, the joint involved being the ball-and-socket joint of the hip.

4. In *Rotation* the bone moves round an axis, as seen in the movements of the *atlas* on the *axis*.

CHAPTER IV.—THE MUSCLES. MOTION AND LOCOMOTION.

THE MUSCLES.

While the bones form the framework of the body, the main bulk of the substance which clothes them consists of muscular tissue, what is termed **flesh**, which forms about two-fifths of the entire weight of the body. Muscular tissue does not cover and surround the bones in continuous sheets, but is collected into masses, varying in size and length and arranged in different ways. Each separate mass is called a muscle, and is divided off from its neighbours by partitions of connective tissue. Each muscle is supplied with blood-vessels, and with other vessels called lymphatics and nerves, which also have their sheaths of connective tissue; and vessels and nerves also run between muscles on their way to other parts. Over the muscles is a continuous sheet of fibrous tissue, having embedded in its substance a large number of fat cells. It is called **fascia**, and it not only covers over all the muscles, but fills up to some extent inequalities of surface, and gives a rounded and regular appearance. Finally, outside of all is the **skin**. So that if a limb were to be examined, say an arm, after the outer covering of the skin had been removed, the fascia, presenting a fatty appearance, would appear. When it in turn had been stripped off the various muscles would be revealed, inclosed in their sheaths and separable from one another. On pushing some of them aside vessels of various size and nerves would be visible, and not till the muscles had been stripped off would the bones be uncovered. Of course in some places, and particularly in the neighbourhood of joints, the bones come very near the surface, being covered by little else than fascia and skin.

The muscular tissue forming the masses is red in appearance, and it is therefore called **red muscle**. But there is another kind called **white muscle**, found in the walls of blood-vessels, in the coats of the stomach, bowels, and bladder, in the walls of the air-tubes of the lungs, and elsewhere. The two kinds of muscle differ from one another in various other respects. Both are the active agents in motion; but the movement caused by red muscle, for instance the motions of our limbs in walking, in grasping, and so on, which are due to contractions of the muscles of leg or arm, is a movement controlled by our will, while the white muscle exists in organs also capable of contractions, but contractions quite independent of our will, which go on without our willing, even without our knowing. For this reason the red muscle is also called **voluntary** muscle, and the white

involuntary muscle. There is also a difference in structure between the two, the former presenting, when viewed under the microscope, a striped or striated appearance, the cause of which will be referred to immediately, while the latter is smooth and regular in appearance; the one is therefore called **striped** or **striated** muscle, and the other **unstriped, non-striated,** or **smooth** muscle. The two kinds of muscle, then, are **red, voluntary,** or **striated** muscle, and **white, involuntary, non-striated,** or **smooth** muscle.

Structure of Voluntary Muscle.—If a small piece of muscle, that is flesh, be examined under a microscope it is found to be made up of *fibres.* Each fibre is inclosed within a delicate transparent sheath, called the **sarcolemma.** (fig. 31 shows a single fibre which has been torn, the torn ends have separated from one another, and the delicate sheath is seen passing across between the two. Each fibre can be split up longitudinally into a number of little fibres or **fibrillæ**, or can be separated transversely into **discs.** Many views are advanced to explain the striated appearance. The simplest seems to be that a muscular fibre is made up of two kinds of substances, one doubly refractive, the truly contractile substance, which exists in the form of minute columns or pillars (sarcous elements) set in rows across the breadth of the fibre, embedded among the second singly refractive and non-contractile substance. A very slight amount of the embedding material is present between the columns of a row, so that they present the appearance of a continuous dark band. But there is a considerable accumulation of the embedding substance at the ends of the columns of one row, separating them by a clear-looking interval from those of the next row. Thus the dark band alternates with a light band, and the appearance of a cross striation is produced. Delicate membranes, connected with the

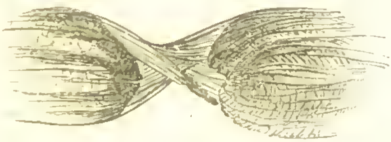

Fig. 31.—A Striped Muscular Fibre with its Sheath.

sarcolemma, cross the fibre like partitions, dividing it into compartments, and these partitions pass across in the region of the accumulation of embedding material, appearing as dark lines in the light band. It is, of course, only with very high powers and special treatment that these details of a muscular fibre can be revealed. They are represented in fig. 32. Under the sarcolemma, and on the muscle substance lie, here and there, nuclei. The fibres, so composed, are inclosed within a sheath, the sarcolemma. Fibres, again, are collected into bundles and inclosed in a connective tissue sheath to form what is called a **fasciculus**; and a number of the fasciculi are bound together by a denser layer of connective tissue to form a muscle.

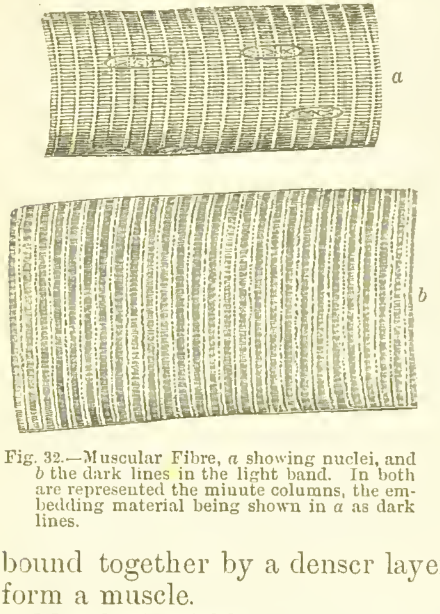

Fig. 32.—Muscular Fibre, *a* showing nuclei, and *b* the dark lines in the light band. In both are represented the minute columns, the embedding material being shown in *a* as dark lines.

Muscle is richly supplied with blood, distributed by means of very delicate thin-walled vessels, which run up between the fibres and communicate with one another by cross branches, forming an exceedingly delicate elongated meshwork about the muscular fibres. It is the blood that gives the red colour to the flesh, which is itself not red but rather straw-coloured. There are also nerves proceeding to muscles, fine nerve-fibrils entering into and terminating in special structures called motorial plates in the very substance of the muscular fibre.

Chemical Constitution of Voluntary Muscle.—Within its sheath or sarcolemma a fibre in the living state is clear, not solid, but semifluid. The semifluid substance can be squeezed out, and is called **muscle plasma.**

It is alkaline in reaction. When allowed to stand, the plasma coagulates, solidifies, and then separates into a watery portion called **serum**, which is acid in reaction, and a solid portion or **clot**, which consists of a substance called *myosin*, an albuminous body. The serum consists largely of water, but contains also albuminous bodies, as well as animal starch or glycogen, and salts, chiefly of potash, and waste substances formed by the action of the muscle. The colouring matter of muscle is the same as that of the blood, namely, hæmoglobin. The clear semifluid substance of the fibres in the living state becomes after death opaque and coagulated. It is the occurrence of coagulation that produces stiffening of the body, or **rigor mortis** (the stiffness of death) as it is called, which comes on some time after the death of a person or an animal. The stiffening may come on *quickly*, within an hour or two after death, or even sooner, if the person has died of an exhausting disease, and then it also passes off quickly. The stiffening may be *long delayed*, as in the case of persons who have died in full vigour, by a sudden accident, for instance, and when it does at length occur it lasts long, and may continue even for several days. In both cases after *rigor mortis* has disappeared the muscles become soft and flaccid, and decomposition ensues.

Properties of Voluntary Muscle.—I. The great property of muscular tissue is **irritability** or the power of *responding to a stimulus.* The response is in the form of contraction, that is, when the muscle is irritated or stimulated, it responds by shortening itself, so that its ends are approximated and it becomes thicker at the middle. The muscle does not shorten itself all at once, but the contraction passes quickly over it in the form of a wave. The usual way in which a muscle is stimulated is by nervous action. The nerve-tubes end, it has been seen, in the fibres, and when an impulse is brought by the nerve the fibres become irritated and shorten themselves. Muscles, however, will respond to other than this usual stimulation. (1) Mechanical means, such as pricking or pinching, will irritate them and cause them to contract.

(2) An electrical current has the same effect. (3) Heat also is capable of producing contractions as well as (4) chemical stimuli. The purpose of contraction is obvious. If one end of the muscle be fixed, and the other attached to something which is free to move, when the muscle shortens itself it will bring whatever is attached to the one end nearer to the other.

A muscle will respond by a single contraction to each stimulus if it be sufficient in amount, and will thereafter relax to be ready for the next contraction. Sometimes the stimuli may follow so quickly after one another that the muscle has barely relaxed after one contraction when it is again called on to contract. If the irritations be still faster, then the muscle may not have time to relax at all between each stimulus. The result is that the muscle remains contracted and rigid. This is the condition of a muscle in cramp, and is called **tetanus**. For instance, when a man seizes the handles of a galvanic machine while it is at work, if the current of electricity be strong enough he finds he cannot let go, his fingers being firmly bent over them. This is due to tetanus of the muscles that bend his fingers, tetanus produced by a series of galvanic shocks causing contractions, the shocks being so rapid that the muscles have no time to relax and remain strongly contracted.

It is to be noted that when a muscle contracts owing to the stimulus received from a nerve it is not the nerve that supplied the energy for contraction. The power of contraction is inherent in the muscle substance, and the stimulus only affords the opportunity for its display. The muscle has energy stored up within it as a barrel of gunpowder has energy stored up within it. The barrel of gunpowder, however, would stand harmless so long as it was left alone. As soon, however, as a lighted match is applied the energy of the gunpowder is liberated and an explosion occurs. So the energy of the living protoplasm of a muscle requires merely a stimulus to set it in operation, such operation taking the form of a rapid movement of contraction.

II. Muscles by their contraction are **able to do work.** Thus if, to the end of the muscle that is free to move, a weight be attached, when the muscle contracts it will lift the weight. It is found, curiously enough, that a muscle contracts better when it has some weight to lift than when it has none. Up to a certain limit with increased weight there is increased work done. The increased resistance seems to call forth increased action of the muscle. When the limit has been passed the muscle quickly fails. Similarly a muscle works best with a certain degree of rapidity, but if the irritations follow one another too quickly, if the contractions are too rapid, the muscle becomes exhausted and *fatigue* arises. "It is the pace that kills."

III. Muscles **develop heat** by contraction.

IV. A **current of electricity** may be obtained from living muscle by special means. It is at its maximum when the muscle is at rest, and diminishes when the muscle is in action.

V. By **tonicity** is meant the condition of tension in which a living muscle normally is. It is this condition of tension or tone that causes a muscle when cut to gape by separation of the edges of the wound.

All of the above are vital properties of muscle. They disappear with the death of the muscle.

VI. But a muscle possesses physical properties whether the muscle be alive or not, which, however, are best seen when the muscle substance is living. These are **cohesion,** the force by which the muscle resists tearing, and **elasticity,** the property by which muscle yields to a stretching force, and which enables it to return to its original length if the stretching has not been excessive.

Muscles are connected with bones not directly but through the medium of tendon. The mass of flesh tapers off as it were towards the ends, where the fibres pass suddenly into tendon, which consists of bundles of white fibrous tissue already described (in Chapter II.). The tendon presents the appearance of a white glistening cord, sometimes flat but often cylindrical, and of considerable thickness. The mass of flesh composing the muscle is called the *belly* of the muscle. One end is usually attached to a bone more or less fixed, and is called the *origin* of the muscle. The other end is attached to the bone meant to be moved by the contraction of the muscle, and is called the *insertion* of the muscle. Sometimes the tendon runs down the centre of the muscle, and the fibres run obliquely into it, the tendon occupying the same position that the quill does in a feather. Sometimes again the tendon is spread out on the surface of the muscle in a flat expansion, in which case it is called an **aponeurosis**.

White, Involuntary, Non-striated, or Smooth Muscle consists of spindle-shaped cells, having an elongated nucleus in the centre (fig. 33). The cells are united to form ribbon-shaped bands, not masses like those of striped muscle. This kind of muscle responds much less rapidly than the former kind to irritations, and the wave of contraction passes over it more slowly. It has been mentioned that this form of muscle is found in the walls of the stomach and bowels, and it is irregular and excessive contractions of the muscular walls of the bowel that produce the cramp-like pains of colic. Colic is, in fact, due to a tetanus of involuntary muscle. The purpose of involuntary muscle in the walls of blood-vessels, stomach, &c., is mentioned in considering these organs.

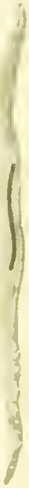

Fig. 33.—A Spindle Cell of Involuntary Muscle, highly magnified.

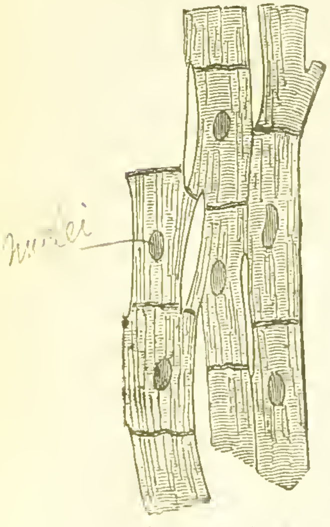

Fig. 34.—Involuntary Striated Muscle of Heart.

The kind of involuntary muscle found in the heart consists of quadrate cells, transversely striated, but without sarcolemma, having oval nuclei in the centre (fig. 34).

They join end to end to form fibres, and the cells branch to form junctions with neighbouring cells. One might, therefore, speak of involuntary *striated* muscle, the heart muscle being its solitary illustration.

Synovial Sheaths and Sacs.

It will be readily understood that the tendinous cords moving so frequently on the surfaces of bone, and over bony prominences, would be liable to develop friction and heat to an extent that might be injurious, unless some means existed for rendering the motion as easy as possible. This is effected by means of **sheaths** which surround tendons. The sheaths form a double lining round the tendons, and the opposed surfaces are lined by synovial membrane, already noticed as one of the structures entering into the formation of joints. The membrane secretes the fluid synovia, which lubricates the sheath in which the tendon slides, and so facilitates the motion. Such synovial sheaths are specially well marked in the tendons of the hand and foot.

Besides sheaths lined with synovial membrane, little sacs similarly lined, and containing fluid, exist in special places between two surfaces which move upon one another to any great extent. Such sacs are called **synovial sacs,** or **synovial bursæ,** or simply **bursæ.** For instance, the movement of the knee-pan in front of the knee-joint has been already referred to. This motion, so constant in walking, would be sure to produce undue friction and heat, and consequent inflammation, were it not for the interposition of such a sac between the upper surface of the joint and the deep surface of the knee-pan. Again, the knee-pan moves underneath the skin, and, to prevent friction between its upper surface and the skin, another synovial sac or bursa is interposed. So that the knee-pan is between two bursæ, one superficial, just under the skin, the other deep beneath the bone. Similar, though smaller, sacs are found over the point of the elbow, over the knuckles, over the malleoli—the outer and inner projections of the ankle-joint—and over various other prominent points, the great trochanter of the thigh-bone for example. They may also be present between two tendons or two muscles. It is important to notice the bursæ, as they fulfil a very important duty, and are besides liable to disease, and specially to various forms of inflammation.

MOTION AND LOCOMOTION.

The active agents of movement in the body are the muscles, which, by their contraction, cause the bones to move one on the other, the motion being permitted owing to the union of bones to one another being accomplished through the medium of joints. Of course if all the bones were *rigidly* connected with one another all movements would be impossible. Now the muscles, bones, and joints are related to one another in different ways in order to make the movements more effective for different purposes. The bones form **levers**, the attached muscles supplying the *power* for moving them, the joints being the *fulcrum* or point of support, while the *resistance* is supplied by the weight of the limb, the weight to be lifted or the force to be overcome. In mechanics there are three orders of levers described, according to the relative positions of power, fulcrum, and resistance; and it is found that all the movements of bones on one another can be referred to one or other of the three classes of levers.

Fig. 35 shows a **lever of the first class**, where the fulcrum (F) is between the weight to be lifted (W) and the power (P). There are several examples of this kind of lever in the human body. The head supported on the atlas is a good example. The joint between atlas and skull is the fulcrum, the resistance is the weight due to the part of the head and face in front of the joint, which tend to produce falling down of the chin on the chest,

aha!

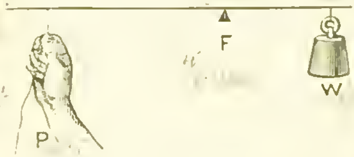

Fig. 35.—Lever of the First Class.

and the power is behind, where the muscles from the neck are attached to the back of the skull. The effect of this particular arrangement is to keep the head steady, balanced on the vertebral column, and it is easily seen how well adapted this kind of lever is for such a balancing purpose. It is therefore called the **lever of stability**. The vertebral column is balanced on the haunch-bones, and the leg is balanced on the foot by a similar arrangement, the hip-joint in the former case, and the ankle-joint in the latter, being fulcrum. This lever is also used in the body more directly to effect movement. When the forearm is straightened on the arm the elbow-joint is fulcrum, the power is supplied by the triceps muscle *behind*, and the resistance is the weight of the forearm *in front* of the fulcrum (fig. 36).

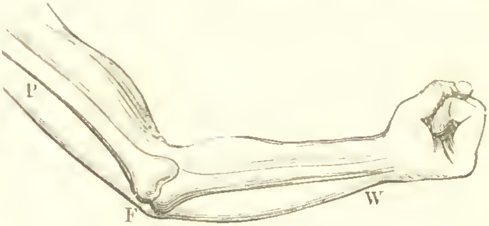

Fig. 36.—Lever of the First Order, illustrated by straightening of the Elbow-joint.

In **levers of the second class** the weight is between the power and fulcrum (fig. 37). It is not common in the body. Standing on tiptoe, however, is an example. The fulcrum is afforded by the toes, in contact with the ground; the power is the action of the muscles of the calf, and between these is the weight of the body transmitted down the bones of the leg to the foot (fig. 38).

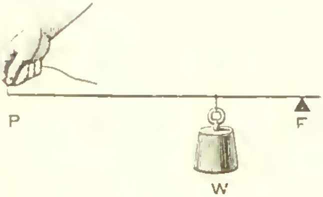

Fig. 37.—Lever of the Second Class.

In levers the force exerted is always proportional to the distance between the fulcrum and the point of application of the force. Now, in levers of the second order the distance between the power and the fulcrum—called the power arm—is greater than the distance between the weight and the fulcrum—the weight arm. So that a force, acting through the greater distance between the power and fulcrum, would be able to *overcome* the same force acting through the smaller distance between the weight and fulcrum, just because, though the forces were the same, the power arm was longer than the resistance arm. In other words, a smaller power would be able to overcome a larger resistance, because of its greater distance from the fulcrum. This lever is therefore called the **lever of power.** This lever has the disadvantage that the power must always move through a greater distance than the weight.

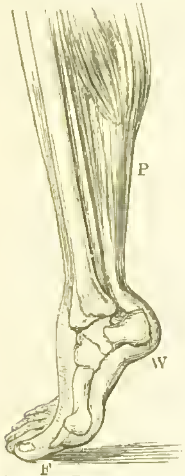

Fig. 38.—Lever of Second Order, illustrated by standing on tiptoe.

In **levers of the third class** the power is between the weight and the fulcrum (fig. 39). It is common in the human body. In bending the forearm on the arm the power is supplied by the biceps muscle attached to the radius, the fulcrum is the joint at one end of the lever, and the weight is at the other end—the weight of the forearm.

It will be remembered that at the elbow-joint an illustration of a lever of the first order also is afforded *in the extension* of the joint by the triceps muscle.

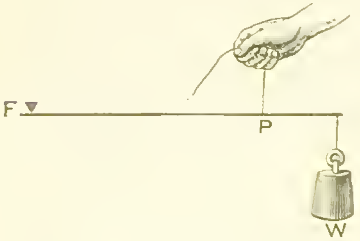

Fig. 39.—Lever of the Third Class.

This is the **lever of rapidity,** for it will be observed that a small movement of the biceps will produce considerable movement of the hand. It is, however, a lever that loses power, for, unlike the last case, here the weight arm is long and the power arm short.

In all the movements of the body these mechanical arrangements are exhibited.

Standing in the erect posture is the position which requires least muscular exertion, the different curves of the spinal column aiding in balancing the trunk, and the various joints being so constructed that only a certain amount of steadying action is required on the part of the muscles, the muscles of the calf, for instance, preventing the falling forward of the leg. In the erect posture, too, the body fulfils the necessary condition of having its centre of gravity within its base of support. Thus, a line dropped from the centre of gravity, which is in front of the sacrum, would fall between the feet a little way in front of the ankle-joints.

In **walking** the weight of the body is supported alternately by one limb and then the other, being hardly balanced on one limb before it is thrown to the other. At the moment when the advanced foot has reached the ground the muscles of the calf of the leg behind contract and raise the body on the ball of the toes (fig. 38), thrusting it forwards and to the side. The weight of the body is thus thrown on the advanced leg, and, owing to the forward movement, the leg that is behind swings forwards like a pendulum, and now becomes the advanced leg, and so the process goes on.

In **running** there is a short period when both feet are off the ground. Running differs from walking also in the quick violent contractions of the muscles, and in the fact that the advance is due to muscular effort alone, and therefore there is proportionately a much greater expenditure of force than in walking.

Thus motion and locomotion are dependent upon mechanical relations subsisting between muscles, bones, and joints. When these relations are interfered with there is difficulty of movement greater or less, according to the amount of the interference.

CHAPTER V.—FOOD AND ITS DIGESTION.

General Sketch.—The digestive system includes all those organs that are connected with the function of **alimentation**, the function, that is, which has to do with the preparation of food to fit it for gaining entrance into the blood, and with the separation of the nourishing from the not-nourishing portions of the food. What exactly all this includes will be most readily understood by an outline of the course taken by the food from the moment that it enters the mouth, and of the processes through which it passes till all the nourishment is obtained from it that is necessary.

The food taken into the mouth is bruised and broken down by the teeth, being rolled about in the mouth as well, and mixed with a fluid—the **saliva**—which is poured out by certain glands in the walls of the mouth and their neighbourhood—the salivary glands. Then, made up into a mass and well moistened, it is forced into the back part of the mouth, mainly by the action of the tongue, and then carried by muscular movements, constituting swallowing, into the gullet, down which it passes to reach the stomach. Arrived in the stomach it is submitted to the action of a new fluid—the **gastric juice**—whose operation is aided by the heat of the parts and by a slow movement which propels it round and round the bag of the stomach. 3 or 4 hrs. After the lapse of some time, from one to three or four hours, the process in the stomach is completed, and the food has become converted into a more or less fluid mixture called **chyme.** Some of its nourishing elements pass without delay out of it into the blood-vessels which line the walls of the stomach; the rest escapes from the stomach into the canal of the small intestine, where it at once meets with three other juices—the **bile**, from the **liver**, the **pancreatic juice**, from the **pancreas** or **sweet-bread**, and the **intestinal juice**, poured out from the wall of the intestine itself—which attack the substances that have escaped the action of the gastric juice. Along the canal of the intestine the chyme is propelled, forced onwards by gentle circular contractions of the walls of the canal; and all along its course there are being slowly abstracted from it all the nourishing elements it possesses. From the small intestine the remains of the food pass into the large intestine, along which they proceed much more slowly owing to the form of the large bowel. During their slow progress much of the watery material that remains is removed, and finally the waste matters, having obtained some degree of consistency, accumulate in a dilated portion at the end of the large bowel, termed the **rectum**, till they are expelled by an effort of will. We have then to consider in detail the alimentary tract or canal extending from the mouth to the end of the rectum, the juices met with at various intervals, the glands which produce them, and the actions they exert upon the food, and the means by which the digested food is made to give up its nourishing portion to the blood.

The **alimentary canal** is the anatomical name given to the whole length of the canal or passage along which the food is carried. Its average length in the adult is about thirty feet, or about five or six times the length of the body. The mouth, with the teeth and salivary glands, is situated in the head; the gullet, whose upper wide portion, situated at the back of the mouth, is called the **pharynx**, is chiefly in the cavity of the chest, lying against the vertebral column; and it passes through the muscular partition that separates the chest from the belly—the **diaphragm**—to open into the stomach. The stomach and remaining portions of the canal are placed in the cavity of the belly, which conceals them, and which is therefore called the **abdomen** (Latin *abdere*, to conceal).

The appearance and position of the different parts of the alimentary canal will be better understood by referring to the accompanying wood-cut and description (fig. 40).

The opening out of the rectum on the surface of the body is called the **anus**. At this place there is a double constriction, caused by circular bands of muscular fibre round the canal. These bands form what is called the sphincter of the anus, and prevent the accumulated matters in the rectum passing out until the muscle is relaxed by an effort of will.

Observe that the bend at the sigmoid flexure (*m*) helps to relieve the rectum and sphincter of the anus of the pressure of the matter contained in the descending part of the large bowel. Without that relief there might be difficulty in maintaining the closure of the sphincter.

The cavity of the abdomen has been spoken of. It is contained by muscular walls which, directly or indirectly, are supported by the spinal column behind and by the ribs above and the haunch-bones below. In the middle of the back wall of the cavity is the backbone, but it is covered over, and its irregularities and hardnesses masked by muscle and other soft tissues. The abdominal cavity is separated from the chest cavity above it by a partly

a, The gullet, or œsophagus, which is continued from the back part of the mouth to
b, The stomach.
c, The pylorus, the small end of the stomach where it opens into the first part of the small intestine. At the pylorus is a thickened portion of the stomach wall, which acts as a valve to prevent the food leaving the stomach till the proper time.
d d, The duodenum or commencement of the small intestine.
e e e, The second part of the small intestine, called the jejunum.
f f f f, The third and terminal portion of the small intestine, termed the ileum.
g, The cæcum. This is the commencement of the large intestine, and between it and the ileum there exists a valve which prevents the return of any of the contents of the large intestines back into the small. This is called the ileo-cæcal valve.
h, A round worm-like process of the cæcum, which is termed the vermiform process.
i, The first portion of the large intestine, called the ascending colon.
K, The transverse colon.
l, The descending colon.
m, A part of the large intestine which is curved on itself, somewhat in the form of the letter S, and termed the sigmoid flexure of the colon.
n, The termination of the large intestine and alimentary canal, named the rectum.

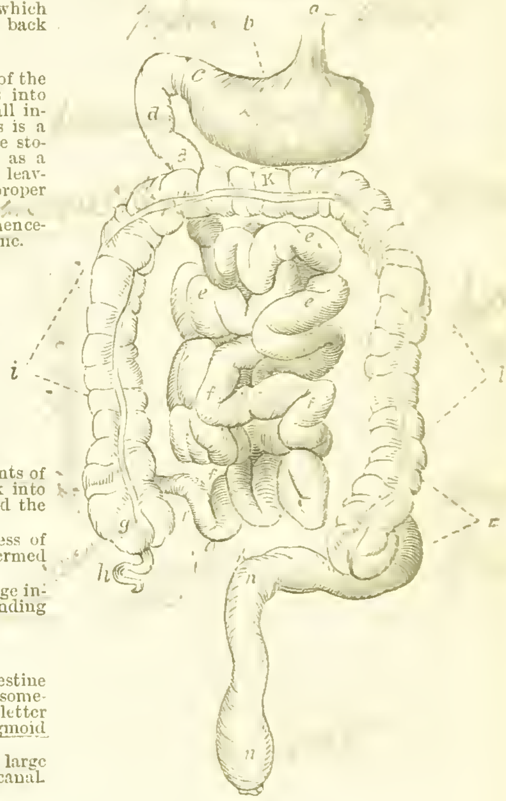

Fig. 40 -The Alimentary Canal.

muscular and partly tendinous partition, the diaphragm, which is arch-like, the top of the arch being directed towards the chest. (Fig. 70, p. 186 will make this more easily understood.) Now it must not be supposed from the diagram (fig. 40) that the intestines lie in a loose heap in this cavity. Lining the cavity, just as, to use a very rough figure, a paper lines the walls of a room, lining the walls of the cavity is a delicate fibrous membrane called the peritoneum. When the peritoneum in its course of lining the walls comes in contact with the large bowel it passes over part of it, just as the paper of a room would pass over, say a gas-pipe which ran along the surface of a wall, and in passing over the large bowel it binds it down to the wall of the cavity. The small bowel is, however, not lying against the wall of the cavity as is the large one, it is out towards the centre of the space. In order to reach it, therefore, the peritoneum from its course over the back wall passes out to reach the small bowel, passes round it so as completely to envelope it, and then passes back to the wall again to continue its course. Thus there is a double fold formed by the membrane as it passes out and as it passes back, and this double fold

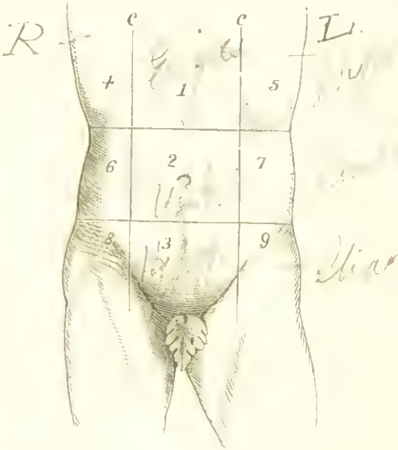

Fig. 41.—The Regions of the Abdomen.

1. *Epigastric Region.*—The right part of the stomach, the pancreas or sweet-bread, and part of the liver.
2. *Umbilical Region.*—Transverse colon, part of duodenum, with some convolutions of jejunum and ileum.
3. *Hypogastric Region.*—Convolutions of lower part of small intestine, the bladder in children and in adults if distended, and the womb in females when enlarged.
4. *Right Hypochondriac Region.*—Right lobe of liver and gall-bladder, part of the duodenum and of ascending colon, upper part of right kidney.
5. *Left Hypochondriac Region.*—Large end of stomach, spleen, narrow part of pancreas or sweet-bread, part of colon, upper part of left kidney.
6. *Right Lumbar Region.*—Ascending colon, right kidney, and part of small intestine.
7. *Left Lumbar Region.*—Descending colon, left kidney, and part of small intestine.
8. *Right Iliac Region.*—The cæcum or commencement of large intestine, and termination of the small intestine.
9. *Left Iliac Region.*—Sigmoid flexure of colon. The rectum lies in the pelvis.

Liver
Spleen
[illegible]
[illegible]

suspends the small bowel from the back wall of the cavity. It is called the mesentery. Besides the stomach and bowels the abdomen contains other organs, the liver, **spleen** (melt), **pancreas** (sweet-bread), **kidneys**, and low down in the pelvis the **bladder** and **generative organs.** The positions of these other organs will be referred to immediately, and will be more fully stated when each comes to be discussed. The general position which most of the organs named occupy can be roughly made out from the outside. Take fig. 40 and study it in relation to fig. 41. It represents the front wall of the abdomen as mapped out into regions by the lines shown on the figure. The regions are marked off by drawing two horizontal lines, one connecting the lower edge of the ribs on each side, and the other by connecting the highest point of the haunch-bone on each side. The two vertical lines are drawn straight upwards from the middle point of the groin on each side. There are thus marked off nine regions, each one being called by a special name, the advantage of them consisting in the list, which anatomists are able to draw up for the guidance of physicians and surgeons, of the different organs which are found to lie beneath each region.

The first region is called **epigastric** (Greek *epi*, upon, and *gaster*, the stomach), because it is over the stomach: the second, immediately below it, is **umbilical**, because it incloses the umbilicus or navel, and the third **hypogastric** (*hupo*, under, and *gaster*), because it is below the stomach. These are the middle divisions. On the right side, the fifth division is right **hypochondriac** (Greek *hupo*, under, and *chondros*, cartilage), because it is the region under the ribs. Below it is the seventh division—the **lumbar** region, and next is the ninth—the **iliac** region, because the region of the ilium, the name for the chief portion of the haunch-bone (p. 51). Similar names apply to similar regions on the left side, left being substituted for right. By referring to page 51 it will be seen that these three lower divisions, namely, the 3d, 8th, and 9th are ranged round the upper edge of the pelvic bones, and that beneath them is the cavity of the pelvis—the lower portion of the abdomen—which has no region marked externally corresponding to it. As already noted, in this lower cavity lie the genito-urinary organs.

These points being understood, by consulting list at fig. 41, p. 73, it will be seen how one could with some ease determine the position of any particular organ from the outside. Or, again, suppose a person to be suffering from pain or swelling at a limited part of the belly, by referring to the list some idea would be gained of the organ or portion of organ that was probably affected.

FOOD.

The Necessity for Food.—A healthy man may be compared to a steam-engine in thorough working order. As an engine uses up fuel and water for the purpose of obtaining from them the energy necessary to perform its work, so a man consumes within his body certain substances in order to obtain from them the energy necessary for his life and activity. The material thus consumed is, in the first instance, obtained from the blood, which is being constantly circulated throughout the body for the purpose of affording to each part of the body its needed supplies. In short, a man by the daily work of his body, whether that work implies merely the movements of heart and chest, the maintenance of the heat of the body, and so on, just what is necessary for life, or implies besides manual or mental labour, a man by the daily work of his life consumes certain parts of his body. Waste goes on within his body. Suppose the waste were allowed to continue, no effort being made to supply the place of what had been consumed, the man would continue to live and work at the expense of his own body. This could not long be endured without danger. The waste must, therefore, be repaired, and food is the means by which this is accomplished. Let us see now what is the nature of the waste. An ordinarily healthy man passes out of his bowels daily, on an average, 5½ oz. of material, a large proportion of which—not less than 75 per cent. indeed—may be considered water, by the kidneys he passes out 56 oz., 96 per cent. of which is water, by the skin, in the shape of sweat, there is expelled a variable quantity, 23 oz. or thereby, of which 99 per cent. is water, and by the lungs 34 oz., of which 10 oz. are water and the remainder carbonic acid gas. Therefore, setting aside for the moment the 25 per cent. of the solid matter removed from the bowels, which will be mainly indigestible or undigested remains of the food, setting that aside, the main bulk of what a man passes out of his body daily consists of water, carbonic acid gas, and certain solid matters contained in solution in the urine, sweat, &c. Now, the chief of these solid matters is a substance found in the urine called urea. Urea is made up of the four elements carbon, hydrogen, oxygen, and nitrogen. Water contains only two elements, hydrogen and oxygen, and carbonic acid also only two, carbon and oxygen. It appears, therefore, that what a man casts out of his body daily consists essentially of four elements, carbon, hydrogen, oxygen, and nitrogen. Now these four elements cast out of the body in the shape mainly of water, carbonic acid gas, and urea, represent the consumption that has been going on in the body to produce the energy necessary for the man's life, even as the smoke, ashes, and steam represent the consumption of fuel and water going on in the steam-engine. It is, consequently, evident that if one could restore to the body daily a quantity of those four elements similar to that cast out one would be able to make up for the waste that had been produced. The purpose of food, then, is to restore an amount of the four elements equal to that used up, to repair the waste.

The Kind of Food required.—One might imagine that if a meal were set down to a man consisting of so many ounces of carbon (charcoal), so many ounces of hydrogen gas, so many of nitrogen gas, and so many of oxygen, he would have all that was required to maintain his strength. But man, in common with other animals, is unable to take the elements, the raw elements, in this way, and make use of them. He needs to have the elements put into combinations that will suit his peculiar organization. Plants are able to take the elements up, however, and transform them into the living substance of their own bodies. Plants combine them, that is to say, for the benefit of man and the rest of the animal kingdom; and then men and animals make use of plants for food, corn, wheat, barley, potatoes, and so on, and so obtain the elements in a combined state which they could not make use of in the simple state. So that the question comes to be, is there a substance containing the four elements named which man can use as a food to repair the waste of his tissues? There is a class of substances, called **Proteids,** which contain all four elements, carbon, hydrogen, oxygen, nitrogen. They are also called **albuminous** substances, because a type of the class is **albumin**—white of egg. Belonging to a similar class is a substance called **gelatin,** obtained by boiling tendons and connective tissues, another called **chondrin,** yielded by boiling cartilage (gristle). Another of the class is found in flour, called **gluten**; and in peas or beans is still another, **legumin.** The curd of milk, from which cheese is made, consists mainly of an albuminous body—**casein,** and in flesh is found another of the class, namely, **myosin.** So that all four elements one could obtain from a quantity of white of egg, curd of milk, or meat. So one might well ask the question, since an albuminous body contains all the required elements, can a man not live on, for example, white of egg alone, or lean meat alone, or a diet of beans or peas alone? Well, an American physician, Dr. Hammond, in 1857 tried some experiments on himself, and limited himself to 1½ lb. of albumin daily, with 4 lbs. of distilled water. On the fourth day he began to experience loss of appetite, headache, and weakness. His disgust at the perpetual sameness and tastelessness of the diet became almost unbearable, and on the ninth day, after severe diarrhœa, he had to give it up. Now, this is not to be wondered at, considering the tastelessness of the diet; but albumin might be made to form the chief portion of the diet, but might be given in a much more palatable form, and might be varied—white of egg one day, lean meat another. Still the attempt to live on an albuminous diet alone would be very difficult to accomplish, N 300 for a reason that will now be given. The total quantity of nitrogen cast out of the body daily by a man, C 4000 under ordinary circumstances, is 300 grains, of carbon about 4000 grains. The quantity of hydrogen and oxygen cast out are replaced by oxygen obtained from the air he breathes, of which he will take into his body by his lungs about 2 lbs. weight daily, and by water, which contains oxygen united with hydrogen, of which 60 to 70 oz. per day are sufficient. Thus, supposing a man to have pure air to breathe and water to drink, he requires 300 grains nitrogen and 4000 grains carbon; that is, 13 grains of carbon for every 1 of nitrogen. In albumin, however, the proportion of nitrogen to carbon is 1 to 3½ instead of 1 to 13, which is as much as to say that a man who sought to live on albumin would get in his food a proportion of 1050 grains (instead of 4000) of carbon for every 300 of nitrogen. In other words, in order to secure his 4000 grains of carbon he would require to take a quantity of albumin that would yield him that amount. But this quantity yields also 1142 grains of nitrogen, which are 842 more than he requires. So that to live on albumin alone he needs a quantity that gives him far too much nitrogen, for which he has no use, and which casts labour on his body to get rid of the excess. To take an example, one would require to eat about 4 lbs. of lean meat to get 4000 grains of carbon, while 1 lb. will yield the required nitrogen. To eat 4 lbs. of meat would mean immense unnecessary labour cast on the digestive organs. Only an albuminous body, however, will yield nitrogen in a condition to be made use of by man, and we are, therefore, face to face with the next problem, is there any other class of foods which could be mixed with the albuminous so as to get the required carbon and nitrogen in the most economic way? The class of food stuffs to which fat belongs contains carbon, hydrogen, and oxygen, without any nitrogen, and a class called amyloid or carbo-hydrates, to which sugar, starch, and gum belong, contains the same three elements without any nitrogen. We thus see that by taking a quantity of lean meat or white of egg just sufficient to supply 300 grains of nitrogen the addition to it of a certain quantity of sugar, starch, or fat will provide the necessary carbon without increasing the nitrogen. Or to take a better example, bread contains carbon in the shape of sugar and starchy matters, and albumin in the shape of the gluten of the flour. It has all the requisite elements, therefore, but in it the quantity of nitrogen is small in comparison to the quantity of carbon. Enough carbon could be obtained out of 2 lbs. of bread, but this quantity would yield only half the amount of nitrogen, so that 4 lbs. of bread would be required to yield a sufficient amount of nitrogen, and that would contain double the carbon necessary. Thus bread has the carbon in abundance, but is deficient in the nitrogen, and lean meat has the nitrogen in abundance but is deficient in the carbon. Unite the two, and you have as a result that 2 lbs. of bread yield very nearly the required amount of carbon and half the required nitrogen, and ¾ lb. of lean meat yield the other half of the required nitrogen and a small quantity of carbon, sufficient to swell that obtained from the bread to the full amount required. A combination, then, of two different kinds of food stuffs, in proper proportions, yields the required substances for repairing the waste of the body, while it throws the least possible amount of work on the body for their digestion. In this consists the economy of a mixed diet. One of the most admirably proportioned of human diets is milk, which contains albumin in the form of curd (casein), that is the nitrogen, and the carbon in the form of fat (the cream) and sugar (the sugar of milk). These are dissolved in water, and thus we have a type of a food fitted not only by its ingredients for the nourishment of the body, but by its form for easy and rapid digestion and passing into the blood.

It is now necessary to remark that there are cast out of the body, besides substances containing the four elements mentioned, other substances belonging to the mineral kingdom—saline bodies, chief of which are salts of sodium and potassium, and particularly chloride of sodium (common salt). These must also be replaced. Bread invariably contains such salts, so also does milk, and meat as well.

To sum up, then, we see that to replace waste there must be introduced daily into the body a certain quantity of water, a certain quantity of solid food containing albumin, and fat, or starch, or sugar, and a small proportion of saline material, and a certain quantity of oxygen gas taken in by the lungs. The quantity of water has already been stated as between 60 and 70 oz. daily, and the quantity of solid dry food ought to be 23 oz. This is the least quantity that is consistent with maintenance of vigour for an ordinarily healthy man doing an average amount of work.

These general considerations regarding food being understood, we may now enter into some detail. From what has been said it will be observed that the foodstuffs required by man fall into six classes, as follows:

1. Watery.
2. Saline.
3. Albuminous or proteid.
4. Fatty.
5. Carbo-hydrate (starch, sugar, gum).
6. Gaseous.

At present we shall neglect the gaseous, as the importance of oxygen gas, and its right to be considered in the light of a food, will be considered in the chapter on respiration (Chapter X.). The remaining five classes are the same as those into which, as we already found (p. 26), the compounds, existing in the body, fall. These five classes form the "proximate principles of food," or the "alimentary principles," for to one or other of these classes all compounds available as food belong. The student should read in this connection what has been said on pp. 23, 24 regarding these classes of compounds. Specially let it be noted that water and saline principles belong to the inorganic, proteid, fatty and carbo-hydrate to the organic kingdom, while of the organic compounds proteid food-stuffs are nitrogenous, containing nitrogen, besides carbon, hydrogen, oxygen and sulphur, and fatty and carbo-hydrate food-stuffs are non-nitrogenous, containing only carbon, hydrogen and oxygen.

The inorganic alimentary principles—water and saline matters.—The importance of water in the body is evident when we recall the fact that it forms a total of about 61 per cent of the body. It is present in every tissue, though in varying quantity, as the table in the foot-note shows;[1] and, as already noted, water is continually being removed from the body by every channel for the expulsion of waste. As regards the saline matters, the importance of common salt has been commented on. About half an ounce of common salt is expelled from the body daily, mainly dissolved in the urine, and it must be promptly restored. Other salts are also expelled—salts of potassium, phosphorus, &c.—which also must be restored.

The organic alimentary principles—proteids, fats, and carbo-hydrates.—The significance of the proteid food-stuff has already been sufficiently commented on. No other kind of food-stuff yields the necessary nitrogen in a form in which the body can make use of it. The principal proteid food-stuffs are milk, eggs, flesh-meat of all kinds, fish, and among vegetable foods the cereals (whose proteid constituent is called gluten), namely, wheat, rye, barley, maize, rice, &c. Potatoes and green vegetables contain also some proteid material, but in much smaller quantity, starch being the principal ingredient of potatoes. Vegetables are specially rich in

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[1] The kidneys are formed of water to the extent of				82·7	per cent.
The bones	,,	,,	,,	22	,,
The teeth	,,	,,	,,	10	,,
The enamel of teeth contains of water			,,	·2	,,

salts. Peas, beans and lentils also belong to this class in virtue of the proteid legumin, which they contain in considerable quantity. Each of these three substances contains nearly 30 per cent of proteids. The fats and carbo-hydrates contain no nitrogen, but only oxygen, hydrogen and carbon. Of the fats it is not necessary to say much. There are three compounds of which fatty matter is made up, namely, *stearin*, *palmitin*, and *olein*. Olein is fluid at ordinary temperatures, and is found in both animal and vegetable structures. Stearin is a solid fat, and exists largely in mutton suet, but is not found in vegetable fats. Palmitin is the chief component of animal fats, and is also found in vegetable oils. Margarin is the term applied to a mixture of palmitin and stearin. To the class of fats belong then the fat of all kinds of flesh, butter, lard, and the various oils expressed from vegetables, seeds, &c., olive-oil, almond-oil, linseed-oil, cocoa-nut oil, palm-oil, &c.

The **carbo-hydrates** embrace the starches, such as sago, tapioca, and arrow-root, the sugars, such as cane-sugar, grape-sugar, and milk-sugar, the gums and cellulose which forms the basis of the walls of vegetable cells and fibres. Treacle, golden syrup, honey, and manna belong to this class.

Now, it must not be supposed that proteid food-stuffs contain only proteid materials to the exclusion of fat, sugar, salts and water, or that carbo-hydrate food-stuffs contain only starch or sugar. Milk, for example, is a proteid, yet it also contains fat in the shape of cream, sugar as milk-sugar, salts and water: wheat is also a proteid, but it also contains starch. Potatoes are also proteid, though they contain far more starch than albuminous material. The presence in a food-stuff of a proteid constituent, however small in amount, determines it as belonging to the proteid class, however much fat and starch it may also contain. Then a substance belongs to the carbo-hydrate class when it contains no nitrogen, but hydrogen and oxygen in the proportion that forms water. It may nevertheless contain fat. In fats the hydrogen and oxygen are not contained in such proportions. In short food-stuffs, though possessing one outstanding feature that determines their belonging to one or other class, yet generally contain proportions of materials belonging to other classes. Further to illustrate this a few tables are subjoined, from which it will be seen that milk contains alike albuminous material, fat, sugar, salts and water, oatmeal contains all these, and starch besides, and so on. It should be noted how the proportion of the different ingredients varies in the different food-stuffs, how rich, for example, oatmeal is in albuminous (proteid) material, and how poor rice is in the same ingredient, while, on the other hand, rice is much richer in starch than oatmeal. Take potatoes, as another example. They are poor in albuminous material, but contain a good supply of starch. Beef contains no sugar or starch, but large quantities of albuminous material and fat. It is thus easily seen how a combination of meat and potatoes provides a good supply of all the necessary alimentary principles. It has been mentioned (p. 78) that a properly proportioned diet should contain 13 parts of carbon to every 1 of nitrogen. The nitrogen should be in the form of proteid, and the carbon may be given in the form of sugar, starch, or fat. Expressing the proportion in terms of nitrogenous and non-nitrogenous food-stuffs, it means that a properly proportioned diet should contain 1 part of nitrogenous food to 3½, or at most 4½, non-nitrogenous. Looking at the table it will be seen that none of the food-stuffs have that proportion. Milk and oatmeal are the two that come nearest this proportion, the milk being on the side of excess of nitrogenous, and the oatmeal excess of non-nitrogenous material.

Quantity of Food required in 24 hours.—This quantity has already been stated as 23 ounces dry solids and between 60 and 70 ounces of water. The 23 ounces do not apply to food in the ordinary condition, in which case it contains, as the table shows, a considerable percentage of water, but apply to food which has been deprived of water. Its components are shown in the table from Moleschott given below.

PERCENTAGE COMPOSITION OF VARIOUS FOOD-STUFFS.

	Water. H_2O	Nitrogenous. C-[illegible]	Starch. CHO	Sugar.	Fat. CH[illegible]	Salts.
Bread, - - - -	37	8·1	47·4	3·6	1·6	2·3
Wheat-flour, -	15	10·8	66·3	4·2	2·0	1·7
Oatmeal, - -	15	12·6	58·4	5·4	5·6	3·0
Potatoes, - -	75	2·1	18·8	3·2	0·2	0·7
Rice, - - - -	13	6·3	79·1	0·4	0·7	0·5
Peas, - - - -	15	23·0	55·4	2·0	2·1	2·5
Cow's milk, -	86	4·1	...	5·2	3·9	0·8
Cheese, - - -	36·8	33·5	...	...	24·3	5·4
Fat beef, - -	51	14·8	...	...	29·8	4·4
Lean beef, - -	72	19·3	...	...	3·6	5·1
Pork, - - -	39	9·8	...	...	48·9	2·3
White fish, - -	78	18·1	...	...	2·9	1·0
Egg, - - - -	74	14·0	...	...	10·5	1·5

ALIMENTARY SUBSTANCES IN A DRY STATE REQUIRED DAILY FOR THE SUPPORT OF AN ORDINARY WORKING-MAN OF AVERAGE HEIGHT AND WEIGHT (MOLESCHOTT).

	Ounces avoirdupois.
Albuminous matter, ...	4·587
Fatty matter, ...	2·964
Carbo-hydrates (starch and sugar), ...	14·250
Salts, ...	1·058
Total, ...	22·859

As shown by the above table, ordinary food contains on an average about 50 per cent of water, so we may reckon the 23 ounces dry food to equal 46 ounces of food in the condition in which it is usually found. This, with 50 to 60 ounces of water, forms the quantity of food required by a person of average height and weight doing a moderate amount of work. The diet for hard work reaches 28 ounces dry solids. In short, the quantity of food should vary with the quantity of work done. The bare subsistence diet, a diet not consistent with active exercise, is between 14 and 15 ounces dry solids daily.

The Uses of Food.—A steam-engine derives the energy necessary for the performance of its work by the expenditure of fuel, usually coal, in its furnace. Every one knows that a fire will not burn if atmospheric air is shut off from it. The main constituent of coal is carbon; and the process of burning, the act of combustion, consists of the union of the oxygen of the air and the carbon of the coal to form compounds of oxygen and carbon, which, in the shape of gases, escape up the smoke-stalk. The coal is said to be oxidized. In this act of chemical combination much heat is generated which raises steam in the boiler, by the pressure of which the engine is driven. Materials of the coal which do not thus combine remain as ash and are raked out of the furnace as waste. Now much the same process goes on in the human body, though, of course, the combustion or oxidation process does not proceed at the same rate as in the furnace of the steam-engine. Food-stuffs, as we have seen, consist of carbon, hydrogen, oxygen and nitrogen, in the case of carbo-hydrates (sugar, starch, &c.) and in the case of fats the first three only. These are taken into the body and undergo a process of slow combustion, by which the carbon and oxygen combine to form carbonic acid gas, and the hydrogen and oxygen combine to form water. The hydrogen and oxygen already exist in carbo-hydrates in the proportion to form water, in fats the hydrogen is in excess, requiring the introduction of other oxygen with which it may combine. There is continually being introduced into the lungs atmospheric air, from which the blood takes oxygen, and thus by the lungs oxygen is continually gaining entrance to the body for the purpose of maintaining the combustion process. Now if carbo-hydrates and fats be completely oxidized, if they undergo complete combustion, their ultimate products are, as we have said, carbonic acid gas and water. They do undergo this complete combustion in the body, and the carbonic acid gas and water thus produced are driven off from the body by the expired air, from the skin and by other channels, just as the products of combustion of coal in the steam-engine pass up the smoke-stalk. By this combustion of food-stuffs in the body heat is generated and the temperature of the body maintained, and energy is produced for the work of the body. If this be true the more such foods are consumed, the greater will be the quantity of carbonic acid gas and water expelled from the body; and if this be true the more work a man does the greater also will be the quantity of these two products of combustion of food. Both these things are so. Let a man rest, a certain quantity of these substances is given off, because combustion is going on slowly to maintain his bodily temperature, and to supply energy for the work of the heart, lungs, &c. necessary to life:

let him now take some vigorous exercise, at once the quantity of carbonic acid gas, &c. expelled increases, so that, indeed, the increased energy he has expended might be measured by the increased quantity of the gas expelled. Here then we have two uses of food, particularly so far as carbo-hydrates and fats are concerned; they are **heat-producers** and **generators of energy.** The whole of these two alimentary principles need not undergo combustion immediately after being introduced into the body. A quantity in excess of present wants may be taken as food. They can be stored up in the body till occasion demands their use. Fat may be stored up as fat under the skin or elsewhere, and fat being a non-conductor of heat a layer of it helps greatly in preventing the loss of heat from the body. The body heat of animals like the seal and whale could not be maintained but for a dense layer of fat. Carbo-hydrates may also be stored up. Glycogen, or animal starch, found in the liver is mainly derived from such materials, and may be stored up to a large extent in the liver. Then the results of feeding experiments conducted on pigs and other animals show that carbo-hydrates may be converted into fat in the body and so held in reserve. The delicacy known as *pâté de foie gras* is made of fatty livers of geese, which have been kept in confinement and stuffed with foods rich in fats and starch. But it has been shown that the quantity of fat which accumulates in the animal under such circumstances is greater than can be accounted for by the fat given in the food, so that some of the carbo-hydrates of the food have become changed into fat.

Hitherto we have taken no account of nitrogen, and have neglected the uses of proteid food-stuffs. One use of such food is plain. All the tissues and most of the fluids of the body contain nitrogen. For growth of tissues, for purposes of development, for repair of the waste of tissues and organs, nitrogen is, therefore, necessary, and proteid food-stuffs, therefore, fulfil one purpose accomplished by none other. It was this that led Liebig to classify food-stuffs as **heat-producers** and **tissue-formers**, but so far as this implies that proteid food-stuffs may not also directly undergo combustion so as to produce heat and energy, it is, as recent investigations have shown, a mistaken classification. Liebig's idea was that proteid food-stuffs were first built up into the various tissues of the body, muscle and nerve, and so on, that when muscle work was performed and nervous action took place, part of the substance of muscle and nerve was consumed, and the waste products of the proteid combustion thus occurring were thrown off, the waste being repaired from some proteid food. Now the ultimate products of proteid combustion will be distinguishable from the fact that they will contain nitrogen. If completely burnt or oxidized outside of the body, proteids yield carbonic acid gas and water like carbo-hydrates and fats, but ammonia besides. Now ammonia consists of hydrogen and nitrogen. All of the nitrogen of the proteid will appear as ammonia and thus the quantity of proteid consumed can be estimated by the quantity of ammonia obtained after the combustion is complete. Now proteids are not so completely consumed in the body as they may be outside of it; the process stops short of the production of ammonia, none of which is cast off from the body. But in the urine there appears a large quantity (300 to 500 grains daily) of a substance called urea, and a few grains (7 daily) of uric acid. Both of these contain nitrogen besides carbon, hydrogen and oxygen. They represent the results of the combustion of proteid, the ultimate product of proteid consumption, as carbonic acid gas and water are the ultimate results of the oxidation of carbo-hydrates and fats. By no other channel is any appreciable amount of nitrogen conveyed out of the body. If, therefore, the amount of urea and uric acid expelled daily be determined, the amount of proteid consumed in the body in its production can be determined. Now if Liebig's view were correct that all the proteid taken as food is built up into the tissues, and that the tissues are broken down as work of various kinds is done, then the amount of urea, &c. appearing in the urine would depend on the amount of work done. Excessive exercise would largely increase the amount of urea cast off, rest would diminish it. This is found not to be the case. *The amount of urea appearing in the urine does, however, increase or diminish with the amount of proteid taken as food.* The result of various investigations goes to show that proteids undergo direct combustion in the body. They are in process of combustion broken up into two parts, with one part the nitrogen goes and finally it appears as urea and uric acid in the urine. The other part consists of the carbon, hydrogen, and oxygen in excess of what is combined as urea and uric acid, and it is oxidized to carbonic acid gas and water with the aid of oxygen introduced by the lungs, or it appears that this part may be converted in the body into fat and stored up as such. In short there is constantly occurring in the body tear and wear of the tissues, and for their repair proteid food-stuffs are employed, but muscular work, even excessive work, does not perceptibly increase the tear and wear, the added expenditure being met by the combustion of the various food-stuffs, proteid as well as carbo-hydrates and fat, which sojourn, so to speak, in the body till consumed, *but are not built up into the tissues before they can be consumed.*

Briefly then carbo-hydrates and fats undergo combustion in the body. Heat is thus produced and energy for the performance of work is liberated. After complete oxidation the final products of carbonic acid gas and water are cast off by the expired air, sweat from the skin, and water from the kidneys. When not required for immediate combustion they are stored up as glycogen and fat till called for. Proteid food-stuffs are used in the development of tissues and in the repair of wasted tissues, but they are also directly consumed without previous transformation into living tissues, part being cast off as urea and uric acid in the urine, part being oxidized to carbonic acid gas and water, thus liberating energy; or part may be converted into fat for further use.

The Destination of Food.—The purpose of food, it has been seen, is to repair the waste going on continually in the body, due both to tear and wear of substance and to consumption of material for the production of heat and energy. The waste occurs in no one part in particular, but in all the tissues of the body. The contraction of a muscle necessary to move a limb means the using up of some material contained in the muscular substance. The beating of the heart means the same thing, the perpetual consumption of some of the particles contained in the heart's substance. The activity of the liver means the constant breaking down some of the material of the small cells of which ultimately the liver is composed. Thinking, feeling, willing, imagining, in the same way are all attended by waste in the nervous tissue. So it is with every organ and tissue of the body.

Every one of these tissues comes into direct contact with the blood. Every organ has its blood supply conveyed to it by vessels large or small according to the size and activity of the organ. The blood-vessel has no sooner entered into the organ or tissue than it breaks up into a number of branches, which in turn send off countless tiny streams that flow through the tissue, pervading it in every direction. As a result the ultimate cells or fibres which form the tissue are constantly bathed by the streams that continually flow past them. Consumption in the cells and fibres is continually occurring, and the stream of blood as continually brings to them the means of repair. It offers to them the raw material needed for their continued industry; and they are able to select from the passing current whatever they require to repair their waste and to provide for their renewed activity. At the same time, as the current goes past, it is a convenient channel for the removal of the products of waste, that must not be allowed to remain in the tissues. The waste, then, occurs in the tissues, the means of its repair are obtained from the blood. In the end it is the blood that is impoverished. From it the drain of nourishment takes place. So long as it is of proper strength and in proper quantity the renewal for the wasted tissues is provided. Thus due provision is made for the nourishment of the tissues if a proper condition of the blood is maintained. The food we take is, then, first of all directed to renewing the blood and maintaining its efficiency. While, therefore, the ultimate purpose of the food is for the repair of waste, its immediate destination is the blood. How does it get there? is naturally the question. It must pass into the blood-vessels out of the cavity of the stomach and the canal of the intestine; but how? There are no visible openings communicating with this canal on the one hand and the blood stream on the other. There is no vessel or channel which acts as a medium of communication between the two.

In 1837 a Frenchman named Dutrochet described some remarkable experiments made by him. He found that if he took a tube open at both ends, one end being of a bulb shape, and if he closed the bulb-shaped end with a piece of animal membrane, a piece of bladder, for instance, then filled the bulb and tube with a strong solution of salt, and dipped it into a glass jar containing water, two currents were set up through the membrane. A current of water passed from outside through the membrane into the salt solution, so increasing the quantity of liquid on that side that it rose in the tube. At the same time salt in solution passed through the membrane into the water outside and could be detected there very soon. Anyone can repeat this experiment for himself, and, provided the solution be strong enough and the bulb be kept dipping in the water outside, the liquid will continue to rise in the tube of the bulb for days, so that many feet of tubing have to be added end to end. At the close of the experiment a very large quantity of the salt will be found to have passed into the water outside. The process by which the water passes through the membrane into the bulb is called **endosmosis.** Since the days of Dutrochet many experiments have been made of a similar kind. Sugar and salts of all kinds are capable of producing the currents and of passing in solution through animal membranes. Instead of the water a solution of salt may be placed in the jar outside, and, provided the strength of the outer and inner solutions is different, the same interchange will go on through the membrane, or solutions of two different substances may be used with a like result. The general result may be put in this way, whenever there are two different solutions, separated only by an animal membrane, an interchange will take place between them through the membrane.

Now let this be applied. In the stomach and intestinal canal there is a quantity of liquid food, to a great extent a liquid containing many substances in solution. In the walls of the stomach and bowels there is flowing a stream of blood, another liquid containing many substances in solution. These two liquids are separated from one another by the extremely thin walls of the channels along which the blood flows, and by a thin portion of the wall of the intestinal canal, in short, by an animal membrane. The liquid in the alimentary canal contains a much larger quantity of dissolved substances than the blood. The inevitable result will be that an interchange will take place between the blood and the contents of the stomach and bowels, resulting in the passing through the wall of the intestinal canal into the blood of the dissolved substances of the food. A continuation of the experiments of Dutrochet, especially those made by Graham, the late Master of the Mint, throws further light on this subject.

DIGESTION.

The Purpose of Digestion.—The experiments referred to on the previous page show that while substances like sugar and salt readily pass through the animal membrane, other substances like albumin, starch, gum, and fat pass hardly at all. Suppose that into the bulb, closed by the animal membrane, a solution of salt, starch, sugar, and white of egg be placed, and then that the bulb be dipped into the jar of water. After some time, if the water outside be in sufficient quantity, all the salt and sugar will be found to have passed out of the bulb, but none of the starch or white of egg, which are still retained. Accordingly, when one takes a meal of bread and meat the contents of the stomach will consist of a liquid containing albumin, obtained both from the meat and bread, fat from the meat, starch and sugar from the bread, and salts of various kinds from both. The sugar and salt will readily pass through the animal membrane of the intestinal walls into the blood, but the albumin, fat, and starch never will. Yet as it is absolutely necessary that they also gain entrance to the blood, it is obvious that they must undergo some change that will confer on them the power of passing through animal membranes. Now, starch can be converted into sugar, and sugar can pass through membranes, and albumin can be converted into a substance called peptone, which also can pass through membranes. The power of converting starch into sugar is possessed by the saliva from the salivary glands, and by the juice poured into the bowel from the pancreas (sweet-bread), and the power of converting albumin into peptone is possessed by the gastric juice poured out from glands in the walls of the stomach and by the juice from the pancreas as well. Fat, again, cannot pass through a membrane, but fat and soda make a soap, which can pass through. Now, the bile is an alkaline fluid, it contains a large quantity of soda salts. It mixes with the fat in the small intestine, and so saponifies it—makes it soap-like—that it becomes possible for it also to pass through a membrane. The story of digestion is practically this, then, that the food we take must get into the blood, but to get there it must pass through the walls of the stomach or bowel, interposed between it and the blood; to pass through these walls it must first be made into a solution; therefore the food is broken down by the teeth and mixed with fluids poured into it from various glands: with no further change the salts, sugar, and similar substances can pass at once through the animal membrane into the blood, but the albumin, fat, and starch cannot: they are, therefore, acted on by the juices till they are converted into substances that can pass. The whole purpose of digestion is, therefore, to make the food into a condition that will enable its nourishing elements, albumin, fat, starch, sugar, and salts, to pass into the current of blood circulating in the walls of the stomach and intestines.

Having thus attempted to understand in a general way why food is needed, what purposes it serves, and what changes it undergoes, and what is the meaning of digestion, we shall proceed more particularly to consider in proper order the details of the digestive process and the organs concerned in it.

Secretion.

The juices required for digestion are prepared, from materials derived from the blood, in organs set apart for the purpose, and called **glands**. The process by which they are prepared is called **secretion** (Latin *secerno*, I separate). This differs from the process of excretion (see p. 213) in that by it materials are separated from the blood *for further use in the body*, while by the latter process materials are separated from the blood *to be cast out of the body*. The means by which secretion and excretion are effected are, however, identical. The gland consists essentially of a basement membrane, on one side of which are found actively growing cells, on the other side is a plentiful current of blood, flowing in exceedingly thin-walled vessels (capillaries). The cells are able, through the basement membrane and blood-vessel walls, to select from the blood whatever materials they require, which they elaborate into the particular secretion. Fig. 42 illustrates diagrammatically the kind of apparatus required for the purpose. The basement membrane with its lining of cells and its blood-vessels may become infolded into the form of a short simple tube, as in the glands of the stomach (p. 102) or small intestine (p. 105), or the tube may be of considerable length and may be coiled to economize space, as seen in the sweat glands of the skin (p. 228). The walls of the tube may be thrown into folds or little recesses, as seen in the sebaceous glands of the skin (p. 230), and when several of these are conjoined a compound gland is produced, called racemose from its resemblance to a bunch of grapes (Latin *racemus*, a cluster of grapes). Such a gland is seen in those for the production of saliva.

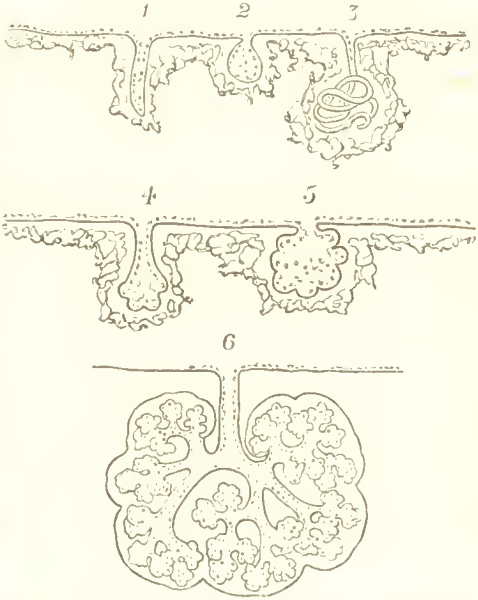

Fig. 42.—Diagram of the Structure of Secreting Glands.

The continuous line represents the basement membrane. The dotted line represents the position of the cells on one side of the basement membrane. The irregular line shows the position of the blood-vessels. 1 shows the simple tubular gland. 2 indicates how the mouth may become shut and a sac formed. 3 represents a coiled tube. 4 and 5 indicate the formation of recesses to produce a sacculated gland, and 6 is a plan of part of a racemose gland (Sharpey).

Fig. 42 also shows the channels or ducts along which the prepared fluid may pass to its destination.

The formation of the secretion is controlled by the nervous system in two ways. The supply of blood is regulated by nervous control. Other things being equal the more blood that flows to the gland, the greater is the amount of its raw material and the more copious its secretion, and the less the supply of raw material the less copious the secretion.[1] A German, Pflueger, has shown in the case of the salivary glands that filaments of nerves reach the very cells of the gland, and thus nerve influence directly controls the activity of the cells

The Digestive Apparatus.

The **Mouth** is a cavity formed by the lips in front, cheeks at the side, tongue below, and palate above. The roof of the mouth derives its bony part from the upper jaw-bone on each side and the palate bones behind (see p. 44); the bone is covered by the mucous membrane (*c*. fig. 43) of the mouth. Reference to fig. 43 will show that the bone (*a*) forms only the front portion of the palate—the hard palate as it is called, for the bone stops short at *b*, and the continuation is effected by mucous membrane and muscular substance as the soft palate, of which the uvula (*u*) is a part. The hard and soft palates form not only the roof of the mouth but also the floor of the cavity of the nose (*n*, fig. 43), so that they partition off the nose from the mouth. Now sometimes this partition is not properly developed, and a cleft exists in the soft palate. The cleft may extend forward some distance and may involve the hard palate, so that the partition is incomplete and a fissure more or less wide permits of an unusual means of communication between the mouth and nose. The result is a very serious defect of speech, the air being sent up into the nose. The mouth is continued behind into the throat, the separation between mouth and throat being marked by a constriction, called the **isthmus of the fauces.** This constriction is formed of fleshy pillars—the pillars of the fauces—which arch up from the sides to form the **soft palate or velum;** and from their meeting place in the middle of the arch there hangs down a portion, termed the **uvula** (*u*). At each side, where the pillars begin to arch up, is an almond-shaped body—the **tonsil,** which ought not to be prominent at all, but which swells and projects towards the middle line in inflamed throat, threatening often to block the way from the mouth into the throat. The tonsil is seen in the figure partly hidden by the uvula. The whole mouth is lined with **mucous membrane.** This membrane is really in its essence the same as the skin which lines all the external parts of the body. On referring to the chapter on the skin it will be seen to be of two layers—a deep one of a fibrous structure, rich in blood-vessels and nerves, and one on the surface of this, consisting of cells only with no vessels or nerves. In mucous membrane the same two layers are found, but they are more delicate and soft. At all the openings of the body the skin becomes modi-

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[1] This nervous control has been proved in detail in regard to one of the salivary glands, the submaxillary (p. 99). A branch of the *facial nerve*, the motor nerve of the face (see p. 279), called the *chorda tympani* branch, passes to the gland. If this nerve be irritated more blood passes through the vessels of the gland, and there is an increased flow of saliva. On the other hand the vessels of the gland are controlled by a branch from the sympathetic nerve (see p. 280) in the neck, and if it be irritated the blood-vessels contract, less blood passes to the gland and the secretion is diminished. When a sapid substance is taken into the mouth an impression is conveyed by the sensory branch of the 5th cranial nerve (see p. 278) to the medulla oblongata, and is thence reflected down the chorda tympani, the result being increased production of saliva and its flow into the mouth.

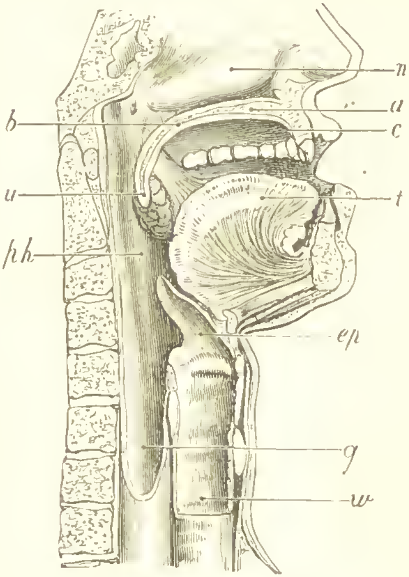

Fig. 43.—Section showing Mouth and Nasal Cavities, Gullet, Windpipe, &c.

t, tongue; *ph*, pharynx; *ep*, epiglottis; *g*, gullet; *w*, windpipe. For other references see text.

fied into mucous membrane, which takes its place and lines all the cavities and channels of the body which communicate with the exterior. The mucous membrane of the mouth is, therefore, continuous with that of the throat, gullet, stomach, and bowels. It is beset with little glands which pour out a fluid to moisten the mouth.

The **Teeth** are imbedded in sockets in the upper and lower jaw-bones. Each tooth consists of a **crown**, the visible part, and one or more **fangs** buried in the socket. The teeth are thirty-two in all, sixteen in the upper, and the same number in the lower jaw. They differ in form from one another, and have different names according to their use. Thus the four central teeth of each jaw have chisel-shaped crowns with sharp cutting edges, and are called, on this account, **incisors**; they have but a single fang. On each side of these central four is one tooth with pointed extremity, the tooth developed in dogs and other animals for holding and tearing—the **canine tooth** (Latin *canis*, a dog). The upper two are also called **eye-teeth.** Behind the canine teeth there follow on each side two **bicuspid** teeth, teeth with two cusps or points instead of one, and having often double fangs; and succeeding them are the **molars** or grinders, three on each side, broad teeth with four or five points on each, and with two or three fangs.

The following table shows the teeth in their order:—

	Mo.	Bi.	Ca.	In.	In.	Ca.	Bi.	Mo.		
Upper jaw,	3	2	1	2	2	1	2	3	=16	=32.
Lower jaw,	3	2	1	2	2	1	2	3	=16	

1 3 4 2

The upright line indicates the middle line of the jaw, and shows that on each side of each jaw there are eight teeth. These are the **permanent set**, which succeeds the **milk-teeth.** The milk-teeth are 20 in number, 10 in each jaw, of which the 4 in the middle are incisors, the one beyond on each side is an eye-tooth, and the next 2 on each side are bicuspids or premolars. The central of the 4 in front in each jaw usually appear at seven months of age. To them succeeds the outer of the incisors at nine months. One of the back teeth appears on each side of each jaw at twelve months, the eye-teeth at eighteen months, and the remainder at twenty-four months. At about the sixth year of a child's life the milk-teeth begin to fall away and give place to the permanent teeth, which appear in the following order:—

Molar, first	6	years.
Incisors	7 to 8	,,
Bicuspids	9 to 10	,,
Canines	11 to 12	,,
Molars, second	12 to 13	,,
,, third	17 to 25	,,

The first of the permanent set to appear is thus the first grinding tooth; and it appears above the gum behind the farthest back of the milk-teeth. The last to appear are the last grinding teeth, which, owing to their lateness of arrival above the gums, have been called the **wisdom teeth**. In some people they never appear above the gum at all.

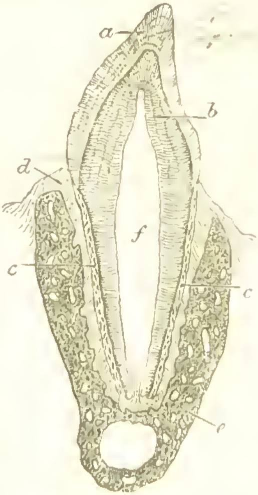

Fig. 44.—Structure of Tooth (magnified).

Structure of Teeth.—Fig. 44 represents the appearance on a cut being carried straight down through a tooth in its socket. In the very centre of the tooth is **the pulp cavity** (*f*), which is filled up with **the dental pulp**, a delicate connective tissue containing a rich supply of blood-vessels and nerves. The vessels and nerves enter by a small opening at the point of the fang. In teeth with two or more fangs the cavity is prolonged, in the shape of a fine canal down each fang, to a little opening at the point of each. Surrounding the cavity on all sides is the substance that forms the main part of the tooth—the **dentine** (*b*). It consists of fine branching tubes embedded in a hard substance. The tubes contain substance continuous with the pulp of the tooth cavity. Dentine is very hard but not brittle, consisting mostly of phosphate and carbonate of lime. Ivory is the dentine of the elephant's tusk. Outside the dentine of the fang is a substance closely resembling bone, and called **crusta petrosa** or **cement** (*c*). In fact it is true bone, but wants the haversian canals (see p. 40). The fang is fixed in its bony socket (*e*) by means of a dense fibrous membrane (*d*) which surrounds the cement as the periosteum does bone. The dentine of the crown of the tooth is not covered by cement but by the **enamel** (*a*), which consists of closely set prisms of a densely hard substance, composed mainly of phosphate of lime and other earthy salts and only 3½ per cent of animal matter. In young teeth the surface of the enamel is covered by a delicate membrane, which answers to the popular term "the skin of the teeth." It is worn off in adult teeth.

3½

The **Tongue** (*t*, fig. 43) is a muscular organ, and is covered by the same membrane that lines the rest of the mouth. On the under surface the membrane forms a fold in the middle line, passing between the tongue and the front of the lower jaw. This fold is sometimes continuous to the tip of the tongue, binding it down and interfering with speech, and in infants with sucking. The upper surface is covered with little projections—the papillæ of the tongue, which are connected with taste, and will be considered in the chapter on the Senses—Taste.

The **Salivary Glands** are three in number on each side of the mouth. Their position is shown in fig. 45. The **parotid gland** is situated on the side of the face in front of the ear; the **submaxillary** is placed below and to the inner side of the lower jaw, in front of the angle of the jaw; and the **sublingual** is on the floor of the mouth between the tongue and gums. The two sublingual glands are thus near to one another, one on each side of the fold beneath the tongue. All these glands belong to the class called **racemose**, from their resemblance to a bunch of grapes. They have little channels or ducts which give off smaller and smaller branches, the smallest branches ending in little pouches or sacs lined with cells, as the stem of the vine gives off smaller stems which end in the pouch of the grape. Groups of the little pouches are bound together by connective tissue, through which blood-vessels pass. Thus the blood stream is brought so near to the cells of the pouch that they can derive from it whatever materials they need for their nourishment and activity. From the blood the cells derive the raw material which they work up into the substance which it is their business to produce. This substance—the saliva—is then conveyed along the small channels or ducts till the common duct is reached which carries the fluid into the mouth. Nerves are also freely distributed to the glands, and it has been found that the activity of the gland is largely regulated by the nerves. Fine filaments of nerves have even been traced to the very cells that line the pouches of the gland. The main duct which conveys away the fluid saliva from the parotid gland (Stenson's duct) opens on the inner surface of the cheek on a level with the crown of the second molar tooth of the upper jaw, where it may be often felt as a slight swelling. The duct of the submaxillary gland (Wharton's duct) opens at the summit of a soft papilla under the tongue. The ducts of the two glands—one of each side—are readily seen on turning up the tip of the tongue. The sublingual glands have a considerable number of ducts opening in the neighbourhood of Wharton's. The purpose of the fluids poured into the mouth from these glands is discussed further on.

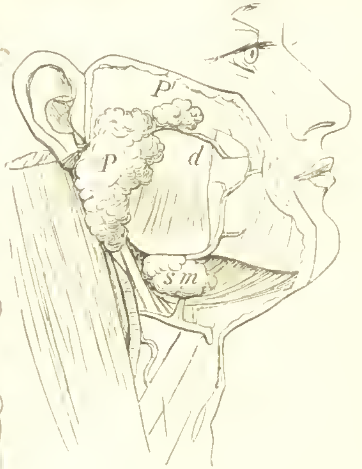

Fig. 45.—The Salivary Glands.

P P', Parotid; *sm*, sub-maxillary. *d* is placed below the duct of the parotid.

The **Pharynx** is the upper end of the alimentary canal, and it forms a blind sac above the level of the mouth (*ph*, fig. 43). The mouth opens into it, and directly above that opening there are two openings, by means of which the nasal cavity communicates with the pharynx. About the same level as the openings into the nasal passages are two apertures, one at each side, which are the mouths of the **Eustachian tubes**, which pass upwards to the cavities of the ears, the cavity of each side being on the inner side of the drum of the ear. By referring to fig. 43 it will also be seen that the windpipe opens upwards into the pharynx, but that this communication can be shut off by the lid of the windpipe (*ep*)—the epiglottis—folding down. Thus there are six openings into the pharynx, and the gullet is the direct continuation of it downwards to the stomach. When one opens the mouth before a glass, the back wall seen through the constriction of the fauces is the wall of the pharynx. The superficial layer of the mucous membrane of the pharynx is stratified squamous epithelium (p. 31) like that of the skin. The membrane is continuous forwards with that of the mouth, upwards with that of the nostrils and tubes leading to the middle ear, and downwards with that of the windpipe and gullet. It is thus that an inflamed condition of that membrane, which may have begun as a sore throat, may extend to the nose, may by swelling block the Eustachian tubes, and so produce deafness, and may extend down into the windpipe, causing irritable throat and coughing. In the membrane is a large number of glands, the excessive secretion and enlargement of which are so troublesome in relaxed and other conditions of the throat.

The **Gullet** or **Œsophagus** (*g*, fig. 43) is the continuation of the pharynx downwards to the stomach. It is about 9 or 10 inches long, and lies behind the windpipe in the neck and upper part of the chest. It passes through the chest, pierces the muscular partition dividing off the cavities of chest and abdomen, and opens into the stomach. The gullet is a membranous tube, lined within by a mucous membrane similar to that of the mouth. It contains a thick layer of muscular fibres in its walls, which by contracting may diminish the diameter of the tube. It is partly by such contractions that the food received from the mouth is passed downwards into the stomach.

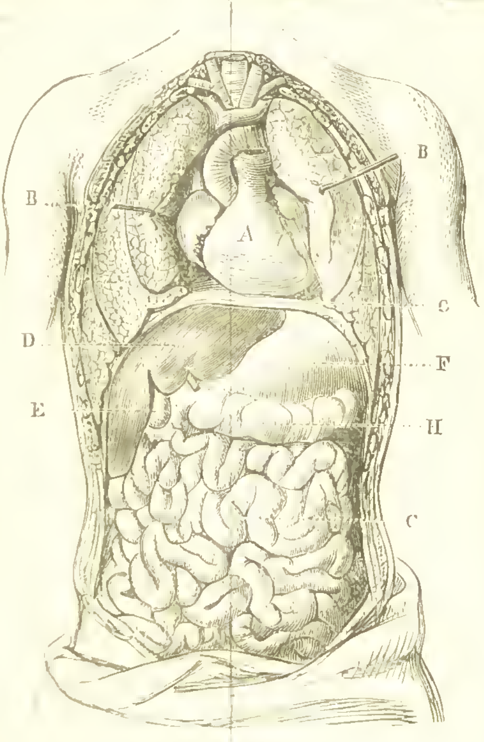

Fig. 46.—The Contents of Chest and Abdomen shown in their Positions.

A, heart; B, B, lungs; C, diaphragm, and a horizontal partition between chest and belly; D, liver; E, gall-bladder; F, stomach; G, coils of small intestine; H, transverse part of large intestine.

The **Stomach** is simply to be regarded as a dilated portion of the alimentary canal. Reference to fig. 41 shows it to occupy a part of the epigastric and left hypochondriac regions of the abdomen. The following figure (46) shows how much of the stomach is in direct contact with the front wall of the abdomen, and how much is covered by the diaphragm (C) above, and the liver (D) to the right. The shape of the stomach is shown in fig. 40, where A marks the entrance of the gullet, and C the junction of stomach and small intestine. It is pear-shaped with the large end to the left and the small end to the right. The large end is called the cardiac end because it is to the heart side. Thus the main bulk of the stomach is under the ribs to the left side. The walls of the stomach consist of three coats, an outer of connective tissue, a middle of involuntary muscular fibre in two layers, the outer running longitudinally, the inner transversely, and an inner coat of mucous membrane, but lined, not with stratified squamous epithelium as that of the mouth and gullet, but with a single layer of columnar cells. The mucous coat is bound to the muscular coat outside of it by a layer of loose connective tissue in which run vessels and nerves. The mucous layer is thrown into folds, and thus presents a corrugated appearance. Glands, in the form of fine wavy tubes, are buried in the substance of the mucous membrane, and open by their mouths on the surface (fig. 47). Each gland is found to be a more or less simple tube lined with columnar cells. **Peptic or gastric glands** they are called. In the tissue between the rows of glands is a large number of very minute blood-vessels. Thus the cells find within easy reach material from which they may abstract what they desire for their continued life and activity. When the stomach is empty the mucous

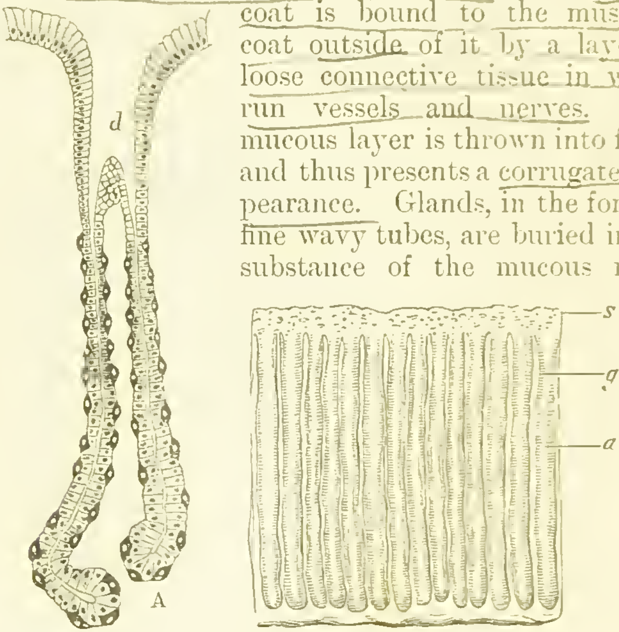

Fig. 47.—The Mucous Membrane of the Stomach, highly magnified.

s points to the surface, *g* to one of the tubular glands, of which *a* indicates the central canal. A is a much more highly magnified view of one gland, which is represented as giving off branches. It shows the columnar epithelium of the surface dipping down into the duct *d* of the gland, from which two tubes branch off. Each tube is lined with columnar cells, and there is a minute central passage. Here and there are seen other special cells, called parietal cells, which are supposed to produce the acid of the gastric juice.

membrane is pale in colour; but whenever food enters it the membrane speedily assumes a rosy tint, due to increased afflux of blood. A little time after, drops of fluid collect at the mouths of the glands and trickle down the walls of the stomach to mix with the food; so that the cells of the glands are thrown into a condition of increased activity by increased quantity of blood supply, and as a result they produce a quantity of fluid—the **gastric juice**—for the digestion of the food. How it does this will be considered further on (p. 112). On looking down on the surface of the stomach with a simple lens little pits or depressions of an irregular form will be seen, and at the bottom of the depressions dark dots; the dark dots are the mouths of the gastric glands.

The **Small Intestine** is continuous with the stomach at its small end. At this point (C of fig. 40) there is a band of circular muscular fibres which keeps the way of communication closed, acting, therefore, as a valve, and called the **pyloric valve**. At appropriate times the fibres are relaxed, and food digested in the stomach is permitted to pass into the small intestine. The first part of the small bowel, about 12 inches long, is called **duodenum** (Latin *duodecim*, twelve) (C D, fig. 40). Into this portion, about the middle, there open the bile-duct from the liver, and the duct from the pancreas (sweetbread), a gland which lies behind the stomach, the large end of which fits into the crescentic curve formed by the duodenum. The succeeding portion of the small intestine has been subdivided into **jejunum** (Latin *jejunus*, empty, because it is usually found so), and **ileum** (Greek *eiléo*, I roll), though there is no distinction between these. The ileum is the last part of the small intestine; and it terminates in the right iliac region (fig. 40) where it opens into the large bowel. The opening is guarded by folds of the mucous membrane forming the **ileo-cæcal valve** to permit the passage of material from the small to the large intestine, but to prevent its backward passage.

The walls of the small intestine consist of similar layers to those of the stomach, but with some remarkable alterations. Like the stomach, the small intestine has muscular layers by whose contraction food in the intestine is propelled onwards. On opening a part of the small intestine and floating it out in water, the inner coat—the mucous membrane—is seen to be thrown into tranverse folds, which are called **valvulæ conniventes**, by which the internal surface of the small bowel is increased. The surface is found to have a velvety feeling, due to innumerable very fine projections termed **villi.** On examining the surface with a microscope these projections take the form of finger-shaped processes from the mucous membrane. They are represented in fig. 48 (*a*). A highly magnified view of a single villus is given in fig. 49, where it is represented as covered with a layer of columnar cells, nucleated. The centre of the projection is formed of adenoid tissue (see p. 125), containing a network of small blood-vessels (*b* and *c*). Besides these, in the very centre is seen a larger vessel (*d*) with a blind extremity. This is the beginning of a **lacteal** vessel, so called because it does not contain blood, but a milk-like fluid (*lac*, milk) obtained from the food in the canal of the intestine. In fact the lacteal is a vessel for absorbing, sucking up, certain of the nourishing parts of the food and conveying them to other communicating vessels, by which they may finally be poured into the current of blood. This will be referred to again in speaking of absorp-

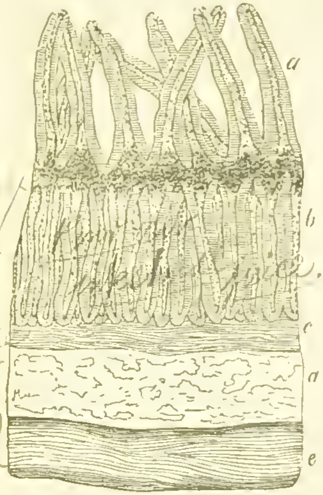

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Fig. 48.—Microscopical Structure of the Small Intestine.

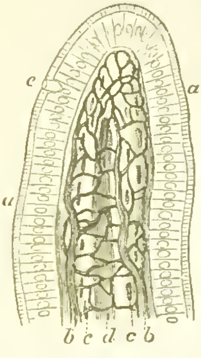

Fig. 49.—A Villus of the Small Intestine, largely magnified. *a*, columnar cells; *c*, goblet cell, modified columnar.

tion. Apart from these projections from the mucous surface, the small intestine presents appearances not unlike those of the stomach. Thus, buried in the substance of the mucous layer, and opening on the surface at the bases of the villi, is a series of tubular glands (fig. 48, *b*) lined with columnar cells. They are called **Lieberkühn's glands,** after the anatomist who first described them; and they pour out the **intestinal juice.** The bases of the glands rest on a fibrous tissue (*c*, fig. 48) between them and the muscular layers of the bowel (*d* and *e*). These glands are found throughout the length of the small and large intestines; the villi, however, diminish greatly in number in the lower parts of the small, and are quite absent in the large, intestine. Towards the beginning of the duodenum a few glands, in clusters like grapes, are found. They are called **Brunner's glands,** but their function is not known. Imbedded in the mucous membrane, also, are found groups of little glands, which are in the shape of closed sacs of lymphoid or adenoid tissue (see p. 125), with no duct or other means of communication with the cavity of the intestine. The closed sacs contain cells and blood-vessels, and are of the size of millet seeds. They are found in groups, called **Peyer's patches,** specially towards the lower end of the small intestine, but similar glands are also found singly here and there scattered over every part of the intestine.

The **Large Intestine** begins in the right iliac region. The small intestine joins it at right angles, and not precisely at its extremity, so that a blind end projects beyond the place of junction—the **cæcum** (Latin *cæcum*, blind). From the place of junction the large intestine passes upwards on the right side, as the **ascending colon,** till the under surface of the liver is reached, where it turns and proceeds across to the left side, as the **transverse colon,** below the stomach. Having reached the left side it turns downwards as the **descending colon** to the sigmoid flexure and the rectum (fig. 40). The large intestine is altogether 5 or 6 feet long. It is much wider than the small intestine. The longitudinal muscular fibres are collected into three bundles, which, being shorter than the canal itself, produce a series of pouches or bulgings in the wall, represented in fig. 40. These pouches delay the progress of the remains of the food, and so permit the nourishing materials to be completely removed. The large intestine possesses the same outer, middle, and mucous coats, with tubular glands, as the small intestine, but the mucous coat has no folds nor villi. Single glands like those of Peyer are also found in the large intestine. The large intestine terminates at the anus (p. 71).

The **Blood-vessels** of the abdominal portion of the alimentary canal have rather a peculiar arrangement which it is desirable to note here. The stomach, intestines, spleen, pancreas, and the mesentery as well, all receive pure arterial blood from branches of the main artery that passes down along the front of the backbone. This blood circulates through the various organs in tiny streamlets. In particular it has already been noted that it is from such arterial blood supply that the glands in the stomach and intestines derive the material for their activity. The blood, after passing through the organs, is collected into veins. Thus the stomach has its own set of veins carrying the blood *away* from it; the intestines have their set, the spleen and pancreas likewise. Ultimately, however, the veins from these different organs unite to form one large vessel, **the portal vein**, which passes to the liver. The liver thus receives all the blood which has previously circulated through the stomach and intestines, which blood, as we shall see, is charged with nourishing material obtained from the food by the process of endosmosis explained on page 90.

The **Liver** must also be counted as a part of the digestive apparatus, since it forms the bile, one of the digestive juices. It is the largest gland in the body, and weighs from 50 to 60 ounces avoirdupois. It is placed just below the diaphragm and on the right side, as may be seen on reference to fig. 46. It extends also across the middle line of the body towards the left side. Its front border reaches just beyond the cover of the ribs when a person is sitting or standing; but when the person lies the liver passes slightly up so as to be completely under cover of the ribs, except for a small portion beyond the lower end of the breast-bone. In women by tight lacing the liver is often permanently displaced, forced downwards out of cover of the ribs. This causes crowding in the abdomen and pelvis, and may serve to displace other organs. When a small piece of liver is examined under a microscope it is found to consist mainly of large many-sided cells, containing a large nucleus and a nucleolus. The cells are represented in fig. 50. The protoplasm of which they consist is very granular, and frequently exhibits a large number of minute bright dots—oil globules. The cells are faintly yellow in colour, and measure the $\frac{1}{1000}$th of an inch in diameter. They are disposed in groups or masses, each little mass being called a lobule. When a single lobule is examined it appears to be of an irregularly circular shape, and the cells are arranged in it in rows which seem to radiate from the centre to the circumference of the lobule. It is the lobules that give the liver its coarse granular appearance when torn. It has been mentioned above that the **portal vein** comes to the liver carrying blood full of nourishing material obtained from the stomach and intestines. When this vein reaches the liver it breaks up into branches, which pass into the substance of the organ, giving off smaller and smaller branches as they go. The smallest branches of the portal vein reach the *circumference* of the lobules, and from this surrounding vessel fine streams of blood pass inwards among the cells to the centre of the lobule, where they reunite into one vessel, a branch of what is now called the **hepatic vein** (*hepas*, the liver). The *central* vessels of the lobules unite to produce larger and larger veins till one vessel is formed which carries all the blood

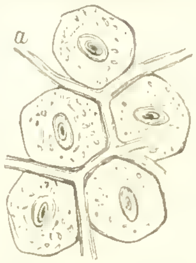

Fig. 50.—Cells of the Liver (very much magnified) with channels (*a*) for the bile between.

away from the liver upwards towards the right side of the heart. The portal vein is thus formed by a set of capillary blood-vessels in the stomach, intestines, &c., and splits up into a similar set in the liver, which in their turn give rise to the hepatic vein. It is to be noted that neither of these vessels carries arterial blood. Yet the liver is not without its supply of such pure blood, brought to it by an artery—the **hepatic artery**—which enters the liver and distributes its blood, not to the cells, but to the connective tissue of the bile-ducts and vessels in the organ, the blood afterwards finding its way, like that of the portal vein, into the hepatic vein.

Besides these branches of the portal and hepatic veins and hepatic artery another set of vessels ramifies in the liver, namely the **bile-ducts**, whose business it is to carry off the bile produced by the activity of the cells. A very remarkable and interesting experiment, performed by a Polish anatomist shows where the bile-ducts originate. This investigator injected into the veins of some animals a particular dye, indigo-carmine. An hour and a half afterwards the animal was killed, and examination of specimens of the liver under the microscope displayed the colouring matter collected round the cells of the liver in channels which were thus for the first time revealed. If the animal were killed sooner, the colouring matter was found in the cells themselves. It thus became apparent that the liver cells seized upon the colouring matter in the blood brought to them, separated it out, and passed it into channels surrounding them. The channels are shown in fig. 50 (*a*). They are the beginnings of the bile-ducts. It may be supposed that, in a similar fashion, the cells of the liver take from the blood flowing past them certain materials from which they prepare the bile, which is then discharged into the surrounding ducts. Along them the bile passes from between the cells out of the lobule into larger ducts, which collect the bile from numerous lobules. These ducts unite with others from other parts of the liver until, in the end, two channels are formed, one of which carries all the bile formed by the right portion of the liver, and the other that from the left portion. These two ducts issue from the substance of the liver and soon unite into one main vessel—the **hepatic duct**, which passes towards the small intestine. On the under surface of the liver is the **gall-bladder**, in which the bile may be stored till needed for digestion. From the gall-bladder a duct passes—the **cystic duct**. It joins the duct from the liver, and the **common bile-duct**, formed by the junction of the two, reaches the first part of the small intestine, through whose walls it passes to open on the inner surface a few inches below the stomach. The bile, then, prepared in the depths of the liver by the liver cells, is conveyed out of the liver by the bile-ducts, and may pass straight down and into the small intestine to mingle with the food. If, however, digestion be not going on, the mouth of the bile-duct is closed, and in that case the bile passes up the cystic duct and lodges in the gall-bladder till required.

Fig. 51 shows the connections of the various parts spoken of, and the figure should be studied in the light of the above explanations.

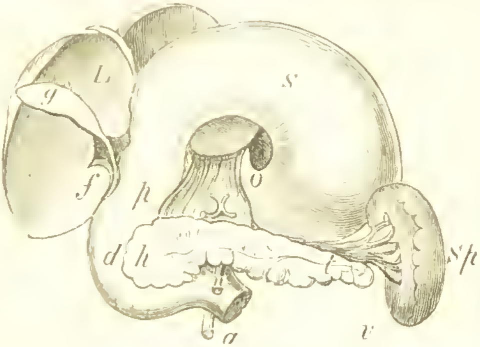

Fig. 51. Relations of the Stomach to the Liver, Pancreas, and Spleen.[1]

The **Pancreas** is a much smaller gland than the liver, weighing not more than 2 or 3 ounces. It lies behind the stomach, and its large end or head lies in the curvature formed by the duodenum. Its position is well shown in fig. 51, where the stomach is represented turned upwards to permit it being seen. In its structure it resembles the salivary glands (p. 98), its ducts terminating in recesses lined with large cells which prepare the juice of the gland. The main duct of the gland runs from one end of the organ to the other, collecting the materials from numerous smaller channels on the way. It finally issues from the gland to pierce the back wall of the small intestine in company with the common bile-duct, and thus is able to pour its secretion among the food which has passed down from the stomach.

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[1] The stomach is represented turned up, *S* being on its under surface. *p* indicates the junction of stomach and duodenum (*d*) at the pylorus. *O* is placed at the junction of stomach and gullet. *L* is on the right portion of the liver, which is also turned up to show *g*, the gall-bladder. *f* is placed to the side of the common bile duct formed by ducts from the liver and gall-bladder. *h–t* is the pancreas, revealed by the turning up of the stomach. *Sp*, spleen. *v*, the part where blood-vessels are connected to the spleen. *n* and *a*, blood-vessels.

The Digestive Process.

We have considered the character and structure of the digestive apparatus, the tract along which the food is conveyed and the various glands in connection with it; and we have seen that these glands pour various juices into the canal to mix with the food, namely, the saliva, gastric juice, bile, pancreatic juice, and intestinal juice. Let us now consider the changes undergone by the food as it passes along the digestive tract, and the part these juices and other agencies play in the change.

Mastication is the first part of the process to which the food is submitted. By this is meant the breaking down of the food by means of the teeth. In some animals, such as the tiger, the lower jaw is movable on the upper in one direction mainly, an upper and a downward movement that permits of tearing the food. In other animals, such as the cow, the movement is from side to side, the grinding teeth being specially employed. In man, however, owing to the shape of the joint between the lower and upper jaws, the lower jaw is movable in many directions, so that a cutting or tearing and a grinding movement as well are permitted. While the food is being thus broken down it is moved about and mixed by movements of the tongue and cheeks, so that every part of it may come under the operation of the teeth. The advantage of this is obvious. The more completely the food is separated up into small portions the more easily will the digestive fluids reach every particle of it, and the more thorough and speedy will digestion be.

Insalivation.—While chewing is going on, the saliva is streaming into the mouth, and is being intimately mixed with the food, and to this the term insalivation is given. The **saliva** is a colourless fluid, without smell or taste. It contains in solution very few saline matters, only about 5 parts in 1000. Its principal element, besides water, is a substance called **ptyalin,** which is a ferment, and possesses the remarkable property of being able to convert starch into sugar. As much as 48 ounces of saliva may be poured into the mouth daily. Thus, in the mouth, and while chewing is being performed, another process is going on which has for its purpose the conversion of starch, which cannot dissolve in water, and cannot pass through an animal membrane, into sugar, which can do both. Besides effecting this object saliva also moistens the food so as to enable it to be made up into a consistent mass fit for swallowing. Saliva aids also in speech by moistening the mouth.

Deglutition.—The food having been thoroughly broken down and mixed with saliva is in a proper condition for deglutition or swallowing. The tongue gathers it up into a bolus or mass and forces it backwards through between the pillars of the fauces into the pharynx, by whose muscles it is grasped. Now, having reached the pharynx, the food, it is easy to see, might be forced in various directions by the contractions of the constricting muscles of the pharynx. Reference to fig. 43 will explain how this comes about. Thus it might be forced back again into the mouth. This is prevented by the contraction of the anterior pillars of the fauces and the forcing backwards of the tongue. The food might pass upwards and get through the openings of the nasal cavity behind. This is prevented by the posterior pillars of the fauces contracting and the soft palate being raised to bar the way. It might pass down into the windpipe, but this is also prevented by the box of the windpipe being quickly raised up under cover of the root of the tongue. The elevation of this part of the windpipe any one may feel by putting a finger on the front of the neck and then swallowing. At the same time as the windpipe is thus raised, its lid, the epiglottis (*ep*, fig. 43), is lowered so as to cover the entrance. The food has thus only one pathway, namely, down the gullet. When it has been forced into this tube the walls contract in a wave-like fashion, and thus propel the food onwards to the stomach. The food does not then fall into the stomach from the mouth. It is carefully conducted thither. This is why a horse can drink though its mouth be below the level of its gullet, and why a man can drink standing on his head. Part of the movements that have been described is under the control of the will, part is involuntary. The forcing of the food backwards is voluntary; but as soon as it has entered the pharynx all the other movements will occur in due order whether we will it or not. They are accomplished by a reflex nervous action.

Digestion in the Stomach.—As soon as the food reaches the stomach that organ becomes active. By the contractions of its muscular walls the food is moved about, and mixed with gastric juice poured out of the gastric glands as described on page 102. The action of the juice is aided by the heat of the parts, a temperature of about 99° Fahr. The gastric juice is acid owing to the presence of a small quantity (·2 per cent) of acid, usually hydrochloric acid. It contains besides a ferment called **pepsin.** Thus the food is subjected to three influences—(1) that of heat, (2) that of acid and pepsin, and (3) that of continual movement. It is owing to the presence of the acid and pepsin in the stomach that digestion is performed. The action of the juice is on albuminous substances. Now albuminous substances are not soluble in water nor can they pass through animal membranes, but by the action of the juice they become converted into what are called **peptones,** which are both soluble and capable of passing through membranes. The juice of the stomach has an action on fat to this small extent, that fat consists of a drop of oil in an albuminous sac, and by the action of the juice this sac becomes dissolved, so that the oil is freed, but no further action on it is effected. Thus it is only on albuminous food-stuffs that gastric juice acts. As a result of the action in the stomach the food becomes converted into a semi-fluid mass called **chyme.**

Digestion similar to that performed in the stomach can be artificially produced. An acid solution of pepsin is required. This is obtained in the following way. The stomach of a pig is taken, opened up, and very gently washed with a stream of water. The inner coat—the mucous membrane—is then stripped off, cut into very small pieces, placed in a bottle among glycerine and water containing a small amount of hydrochloric acid (1½ drachm to every 100 ounces). It is allowed to stand for several days. The glycerine and acid solution extract the pepsin from the glands of the stomach. If now some small pieces of boiled meat, boiled egg, fish, &c., be put into a glass vessel with some water, and if a small quantity of the glycerine extract of pepsin be added, and the whole kept at the temperature of the body—about 99° Fahr.—in a few hours the meat will have undergone digestion. Pepsin wine may be made by adding sherry wine to the glycerine extract. The pepsin powder that may be obtained from chemists is prepared from the pig's or calf's stomach. Rennet, which is used for curdling milk, is a preparation of the calf's stomach, and owes its property to the pepsin it contains. Indeed, what happens to milk on the addition of rennet is precisely similar to what happens to milk passed into the stomach. Owing to the acid of the stomach and pepsin, aided by the heat of the parts, the milk is curdled, and separates into curd and whey. The curd contains the main albuminous constituent of the milk, **casein,** which the pepsin forthwith proceeds to attack. It is thus *seen that the curdling of milk in the stomach is a first and essential part of the process of digestion.* This it is desirable to note, because many mothers, after permitting a child to drink too much milk, are alarmed to see the child, after some time, vomit curdled milk. The vomiting does not alarm them, but the curd does. The explanation usually is that the stomach, being overloaded, rejects some of the milk in a curdled condition, because it has already come under the influence of the gastric juice.

Conditions of Digestion in the stomach. The acid is as necessary to the process as the pepsin, for it has been shown in artificial digestion that pepsin alone cannot act upon albuminous food in a proper way. Hence if the gastric juice be too feebly acid, or if the acidity be destroyed, by soda or other alkalies, for instance, digestion will be imperfect. But an excess of acid equally interferes with the process; thus what is called "acidity of the stomach" produces indigestion in this way. Excess of alcohol also impedes the process.

Overfulness of the stomach will impede the movement of the walls, and therefore the mixture with the juice, and so hinder digestion.

It has been seen (p. 103) how a due supply of blood is necessary for the formation of the digestive fluid. If the blood be occupied elsewhere, as it may be if active exercise be engaged in immediately after food, there may be insufficient for digestive purposes, and a delay in the process results. The secretion of the juice is also undoubtedly under the control of the nervous system. For this reason, no doubt, active brain work immediately after food, either by diverting the nervous activity or by diverting the blood supply, the brain by its activity making great demands on both, may produce indigestion. Gentle exercise, therefore, and repose of mind, are conditions favourable for digestion.

The stomach, like all other organs of the body, should have periods of rest following its periods of activity, and these periods should follow one another regularly.

Time required for Digestion.—Various kinds of food require varying times for digestion. This was proved by a remarkable set of experiments performed. in 1838, on a man named Alexis St. Martin, by Dr.

Beaumont. St. Martin had an opening made in the front wall of the stomach by a gunshot wound. Even after complete healing of the wound a small opening was left through which the mucous membrane of the stomach could be seen, and through which substances could be introduced into the stomach or withdrawn from it. It was found that rice and tripe were digested most speedily, the time required being one hour. Eggs, salmon, trout, apples, and venison occupied an hour and a half, tapioca, barley, milk, liver, and fish, two hours, turkey, lamb, and pork, two hours and a half, beef, mutton, and fowls, about three and a half hours, and veal even longer.

Absorption by the Stomach.—We have seen that the mucous membrane of the stomach is richly supplied with blood-vessels. The blood flowing in them is separated from the semi-liquid food only by a thin animal partition. There is, therefore, no impediment to an interchange taking place between the blood and the food. What the nature of that change will be we have already learned (p. 91). Water, along with any substances in the food that have become dissolved, will pass through the partition and gain access to the current of blood. Thus a considerable quantity of salts in solution, of starch that has become converted into sugar, of albumin converted into peptone, will, without further delay, gain entrance to the blood. Starch that has escaped the action of saliva, albumin that has escaped the action of gastric juice, and fats, will remain in the food, and will be passed on into the small intestine, where the digestive process is continued by other juices.

Digestion in the Small Intestine.—The chyme does not pass all at once from the stomach into the small intestine. It has been found that food already acted on by the gastric juice, if allowed to remain in the stomach, impedes the continuation of the process. The food seems to be digested in the stomach in detachments, and as soon as a portion has become sufficiently digested, the pyloric valve, that we have noted (p. 103) as guarding the communication between stomach and small intestine, the pyloric valve opens, permits that portion to escape into the small intestine, then closes, and opens again as soon as a further quantity of food is ready. The stimulus of the food passing over the openings of the bile and pancreatic ducts causes a discharge of bile and pancreatic juice, which proceed to mix with the food and act upon it.

Alkalin

The **pancreatic juice** is *alkaline*, and contains several ferments; one of them, like saliva, converts starch into sugar, another, like the gastric juice, converts albumins into peptones, and may even proceed further and split up peptones into other bodies; and a third acts upon fats, making them into an emulsion, which is to some extent capable of traversing animal membranes, while fat cannot. Pancreatic juice seems also to split fats up into a fatty acid and glycerine, both of which can be absorbed. Thus starch which has escaped the saliva, and albumin which has escaped the gastric juice, are acted on by the pancreatic juice, and prepared for admission to the blood, the fat unacted on by either of the former juices not escaping the third.

The bile is also alkaline, and of a reddish yellow colour. When it has been vomited it is distinctly yellow, because of the action on it of the gastric juice. As much as $2\frac{1}{2}$ pounds weight of it may be poured into the small intestine of man in 24 hours. It contains a considerable quantity of colouring matter; and its chief ingredients are two salts of soda, the taurocholate and glycocholate of soda. Owing to the presence of these two salts the bile is capable of forming a soap with fat, and thus largely aids the pancreatic juice in enabling oil to become fit for absorption.

Owing to the action of these four juices, aided by the intestinal juice secreted by the tubular glands of the intestine (p. 105), the chyme becomes transformed into **chyle**. The chief distinctions between chyme and chyle are that the former is acid, the latter alkaline. In the former the oil floats in large globules; in the latter it is evenly diffused throughout the liquid as in an emulsion.

and this gives to chyle its milky appearance. The chyle is propelled along the intestine by spiral (peristaltic) contractions of its muscular walls. A function of the bile not yet mentioned is to stimulate these movements, and at the same time to prevent putrefaction of the contents of the intestine. This explains how, when, in diseased conditions, bile is prevented passing into the small intestines, constipation results, and when the stools are passed they are badly smelling, and very light in colour, owing to want of the bile colouring matter.

The special purpose of digestion in the small intestine is then the digestion of fat, while, at the same time, all the other food-stuffs are acted on.

Absorption by the Small Intestine.—The food is propelled along the small intestine, as we have seen, by movements of the muscular walls. The length of the tube is considerable—at least 20 feet—and it is richly supplied with blood along its whole course. Hence what we have observed to occur in the stomach will also occur here, water containing salts in solution, starch converted into sugar, and albumin converted into peptone, will be taken up directly into the blood. In addition some amount of changed fat will enter the circulation. We have noticed, however, special structures in the small intestine, namely, the villous projections (p. 104) containing a loop of blood-vessels, and another vessel—the lacteal. These are specially for the absorption of fat. They dip like fingers into the chyle, and the minute particles of oil pass through their cellular covering and gain entrance to the lacteal. The folds of the small intestine permit a large number of the villi to be present, and a large surface for fat absorption is therefore provided. Thus in the small intestine the nourishing portions of the food are withdrawn in two ways, (1) by blood vessels and (2) by lacteals. The material that enters the lacteals joins the blood current later. It is conveyed by lacteal vessels through the mesentery to reach glands where it undergoes certain changes, and finally reaches a vessel—the **thoracic duct**—which passes up the front of the backbone to reach the root of the neck, where it opens at the junction of the great veins of the left side of the head and left arm. We see, then, that all the nourishing material obtained from the food sooner or later enters the blood.

Digestion in the Large Intestine does not occur to any great extent. The food enters this portion of the digestive tract through the ileo-cæcal valve situated in the right groin (p. 72). Although the great intestine is much shorter than the small, the remains of the food travel through it slowly, the pouches into which the walls are thrown preventing their speedy passage. Time is thus given for fluid matters to be abstracted by the blood-vessels of the mucous membrane. The remains of the food become consequently less fluid, and they acquire their characteristic odour. They are called fæces, and consist of undigested or indigestible materials, and of substances derived from the bowel itself, with a part of the bile from the liver. Propelled onwards by the contractions of the muscular walls, they at last reach the rectum, where their accumulation gives rise to the sensation that ends in the voluntary effort by which they are expelled from the body.

The **nervous relations** of digestion are not thoroughly understood. That digestion is controlled by the nervous system is quite certain. The salivary glands, for instance, have their activity regulated by nerves, some fibres of which find their way to the very cells of the glands. Such direct relationship is not known in the case of the other glands of the digestive tube. This we do know, however, that the formation of the digestive juices is directly dependent upon the quantity of blood supplied to the glands, and that the blood supply is controlled by nervous influence in a way that is explained in treating of the circulation of the blood. Conditions of the nervous system will, therefore, directly or indirectly influence digestion.

Hunger and Thirst.

Hunger and Thirst are two sensations connected with the alimentary function. Hunger is the call of the body for solid nourishment, and thirst the call for water.

Hunger is a sensation referred to the stomach, and, if not appeased, to the intestine later, and is relieved by the introduction into the stomach of a sufficient quantity of nourishing food. It may also be relieved, for a time, by passing into the stomach substances that are not nourishing. It does not seem, however, to be due to mere emptiness of the stomach, for, undoubtedly, after a full meal the stomach is empty for some time before there returns the **appetite** for more food, which is just a modified sense of hunger; besides, alcohol, tobacco, opium, and other narcotics restrain the sensation for some time. The nervous system influences the sensation in a remarkable way. We all know how persons, engrossed with work, may want food for many hours without experiencing any of the sensations of appetite or hunger, and how some impression on the nervous system, such as that caused by the sudden receipt of bad news, anxiety, &c., may abolish the sensation, or may delay its production for a long time. The desire for food may also be relieved by the introduction of nourishing material into the bowel, while hunger may persist even when the stomach is filled with food, if, owing to disease, the food is prevented passing onwards, and the process of absorption is interfered with.

Thirst is a sensation referred to the throat, and, while indicating a deficiency of liquids in the system, it may be produced by the action of drugs like opium, and specially belladonna, or its active principle atropia. Highly salted and spiced substances, by their action on the mucous membrane of the throat and other parts of the alimentary canal, also occasion the desire for water. Thirst is more clearly a general condition of the system than hunger, for it may be rapidly relieved by the passage of water into the blood from injections of water thrown into the bowel, or by the direct injection of water into the veins. The immersion of the body in water relieves for a time, and even the covering of the body with garments soaking with water.

The Functions of the Liver.

The structure of the liver has been described on pages 106 and 107, and its function in digestion has been referred to on p. 116. But the part the liver plays in the digestive process is only one of its duties, and perhaps not the most important. The consideration of its other business is not properly included in a description of digestion. It is advisable, nevertheless, to have a complete view of all the functions of the liver in order to estimate the great importance of that organ in the bodily economy.

The **Functions of the Liver** are indeed not single, but several. As we have seen, it secretes the bile, and therefore ranks (1) as a *secretory organ*, an organ, that is, which elaborates a fluid for use in the body. But the bile is not wholly a digestive fluid. It aids in the digestive process, but it also contains ingredients which are separated from the blood, for the purpose of being *cast out* of the body, because their remaining in the blood would impair its quality. In respect of this the liver ranks (2) as an *excretory organ*, an organ, that is, which separates material of no use to the body, and which is destined to be expelled as waste matter. This will be more easily understood by noting, in detail, the constituents of bile. It contains roughly 86 per cent water, and 14 per cent solid matter. The solid matter consists (*a*) of the bile salts, the glycocholate and taurocholate of soda, (*b*) of colouring matters, (*c*) of fats, (*d*) of inorganic salts, chiefly chloride of sodium (common salt), with a smaller quantity of phosphates, and traces of iron and manganese, and (*e*) of a crystalline substance called cholesterin, a substance found in the brain, and seemingly brought to the liver by the blood. There is also in bile a considerable quantity of mucus, obtained from the bile-ducts and gall-bladder. These substances are in the following proportions:—

Water, ...		85·92 in 100 parts of bile.
Solids—		
Bile salts, ...	9·14	14·08 ,, ,,
Colouring matter and mucus,	2·98	
Fats, ...	·92	
Inorganic salts, ...	·78	
Cholesterin, ...	·26	

Of these the chief are the bile salts, and the colouring matters—the bile pigments. They do not exist already formed in the blood, as do the salts and the cholesterin, and must be formed from materials in the blood by the activity of the liver cells. Now it is the bile salts that act on fats in the alimentary canal and aid in their emulsion and absorption. They appear to be themselves split up into other substances and absorbed, for they are not found in the fæces. The colouring matter of bile is derived from the colouring matter of the blood. The pigment of human and carnivorous animals is *bilirubin*, of a golden red colour. In herbivorous animals it is *biliverdin*, a green pigment. The red pigment is readily converted by oxidation processes into the green. These pigments are cast out in the fæces. Their presence *in the blood* gives rise to the yellowness in cases of jaundice.

(3) The third function of the liver is very different from those already considered. A French physiologist, Claude Bernard, was the first to point out that the liver formed a substance, like starch, which was readily converted into sugar. He called it **glycogen**; it is also called **animal starch.** If an infusion of pieces of the liver of any animal be made, it will be found to be rich in sugar (grape sugar, or *glucose*). But if the liver of an animal, just killed, be rapidly removed from the body and thrown into boiling water, the infusion does not contain sugar. It is opalescent or even milky. By adding alcohol to it a white precipitate of glycogen falls. If to the opalescent infusion saliva be added (which converts starch into sugar,

p. 111), the infusion clears up, and sugar may now be detected in it—the glycogen has been transformed into sugar. Moreover, if water be injected into the portal vein (p. 106) of a liver, removed from an animal, and the injection continued till the water issues from the hepatic vein, sugar will be found in abundance in the water. If the injection be continued till the liver is well washed out, the washings will at last contain no sugar. If the liver be now left for a few hours, and then the injection repeated, sugar will again be found. It appears from such experiments, and many others, that the liver forms glycogen, which is stored up in the liver cells, and that it also contains a ferment capable of transforming the glycogen into sugar. The liver forms its glycogen chiefly from starch and sugar, taken as food, and passing as sugar to the liver by the portal vein. So far as can be learned, the fate of glycogen is to be gradually retransformed into sugar and sent to the tissues, as their needs demand, to supply them with material for their energy and heat. The liver thus has a great purpose to serve in the nutrition of the body. Its *glycogenic function*, as it is called, throws light on the disease *diabetes*, in which sugar appears in the urine.

(4) Fats may be formed or arrested by the liver-cells. Liver-cells usually exhibit bright dots of oil-globules which may so increase in number that the cell appears to contain nothing but fat. The liver of domestic animals, especially of those kept in confinement, tends to become very fatty. The luxury known as *pâté de foie gras* is made of the fatty liver of Strasburg geese. These animals are kept in close confinement and stuffed with rich food, so that the fatty degeneration speedily occurs.

Thus, then, the liver aids in the process of digestion by secreting the bile; it also separates certain waste substances from the blood, and it stores up in its cells substances which are destined to take part in the general nourishment of the body.

CHAPTER VI.

THE GLANDULAR AND ABSORBENT SYSTEM.

THE LYMPHATIC VESSELS AND GLANDS: ABSORPTION.

It has been pointed out on pages 115 and 117 that the blood is regularly receiving fresh supplies of material to maintain its bulk and quality from food that has been taken into the alimentary canal. It has been seen that the nourishing portions of the food gain access to the current of blood by two channels, that watery parts of the food, containing sugar, salts, &c., dissolved in them, can pass directly through the walls of the blood-vessels of the mucous membrane of the intestine, and gain entrance to the blood, but that fatty matters cannot so pass. In the small intestine, however, fat is acted on by bile and pancreatic juice, and, as a result of that action, the fat no longer floats in large globules among the food, but is made into an emulsion, and is broken up into a great number of very minute globules. The fat being scattered through the food in this fine state of division gives it a milky appearance, from which it is called **chyle** (Greek *chulos*, juice). The chyle is separated from the contents of the intestinal canal by the villi (p. 104) of the small intestine, which project from the surface of the bowel to suck up the juices it may contain. The sucked-up juices pass into a vessel in the villus. The vessel has been called a **lacteal**, from the Latin word *lac*, milk, because of the milky appearance of the juice it contains. So that the lacteals are the second channel by which nourishing material passes from the intestinal canal. The process that we thus see performed by blood-vessels and lacteals, by which materials are picked up to be used in the body, is called **absorption** (from Latin *absorbere*, to suck up), and it is a process, as we shall see, not confined to the intestinal canal, but going on in every tissue and organ of the body. The vessels by which the absorption process is carried on are called **absorbents**. We must now follow the course of the chyle in more detail than it was convenient to do on page 117. It appears that this milky fluid which fills the lacteals is not in a proper condition to be poured at once into the current of blood. It may be it is too raw material yet, and must undergo some measure of preparation. The bowel is suspended from the back wall of the belly by means of a double fold of membrane, the mesentery (p. 74). The lacteal vessels are continued up from the bowel between the folds of the mesentery, and pass through glands which are also contained between the folds. [Refer to fig. 52 and its description.] The glands are called the **lymphatic glands of the mesentery**, or, shortly, the **mesenteric glands**. There are about one hundred and fifty of them. In a healthy state each gland should be about the size of an almond, but in certain diseases they are enlarged, and they are seriously affected in consumption of the bowels.

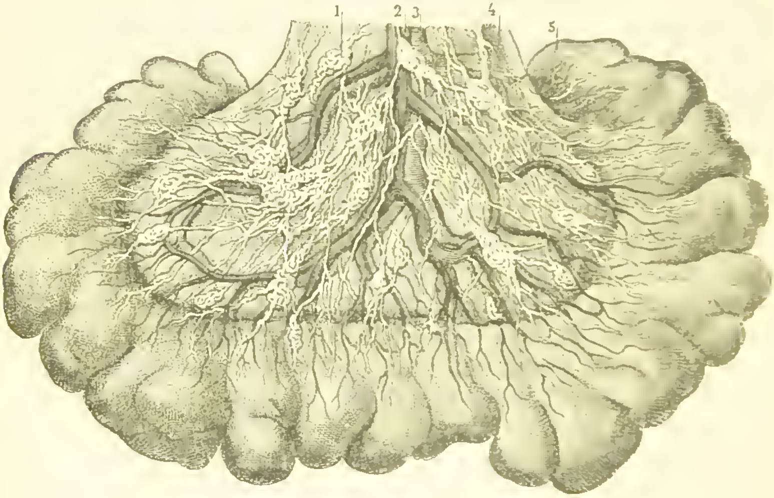

Fig 52. —Mesenteric Glands.

4 points to the membrane of the mesentery from which the bowel (5), seen in folds, is suspended. 1 points to a gland, a large number of which is present, connected to one another and to the bowel by fine lymphatic vessels. 2 indicates a vein, and 3 an artery ramifying through the mesentery and over the bowel

Fig. 53 represents the structure of one of these glands. The gland has an investing coat or capsule (*a*, *a*, *c*), which completely surrounds it. From the capsule fibrous strands (*b*, *b*) pass into the gland, dividing it off like partitions into spaces. The spaces round the circumference (or *cortex*) of the gland are of considerable size, and are more or less oval (*d*, *d*, *d*), while the spaces toward the centre (or *medulla*) are irregular in shape, and smaller (*e*, *e*). The spaces are almost completely filled with masses of material, consisting of a net-work of very delicate connective tissue, in which white cells of various sizes are entangled. This sort of tissue is called **adenoid**, or gland tissue, from the Greek *adēn*, a gland. But the masses of tissue do not quite fill the spaces. Between the outer surface of the mass and the wall of the space are channels, and the channel round one mass communicates with that of another, and those of the circumference communicate with those of the centre, so that the gland might be looked upon as a mass of gland tissue broken up into numerous little clumps by a series of irregularly winding and communicating channels. The channels, moreover, are not perfect fairways. They are crossed and recrossed by spans of the delicate tissue of the gland, so that the whole structure becomes not unlike that of a sponge. Now the lacteal vessels join the mesenteric gland at the circumference (as shown at *f*, *f*, fig. 53), and pour their fluid contents into the channels at the circumference. From them the fluid filters its way to the channels of the centre, bathing and penetrating the gland tissue

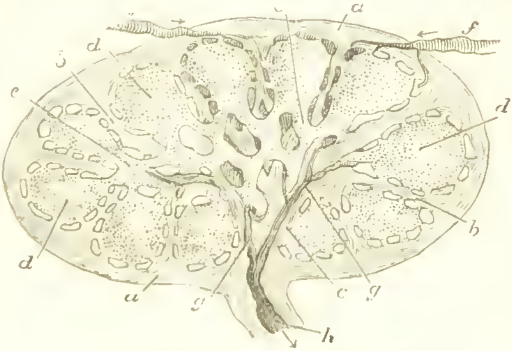

Fig. 53.—The Structure of a Lymphatic Gland.

in its course, and finally joins vessels, identical with *f, f*, at the centre, by which it is carried away from the gland. The outgoing vessel is represented by *g, h*. In this progress through the gland the chyle undergoes some important changes. Before entering the gland it was simply a milky fluid, containing very fine particles of matter in suspension, and being incapable of coagulation, or clotting, when heated; but, on leaving the gland, it is capable of coagulation, and contains numerous white cells, which have been swept away from the gland tissue by the stream. It will now be evident how liable the lymphatic glands are to be irritated and thrown into a condition of inflammation. Suppose the ingoing vessels carry with them irritating material, it filters through the whole gland, irritating in all its course, and swelling and inflammation result. Sometimes this may save the rest of the body. It may be that the gland not infrequently intercepts, like a filter, material which, if permitted to go on, and finally to pass into the blood, would affect the whole body, but which, caught by the gland, expends its whole force on it, so that while the gland suffers the rest of the body escapes. Having issued from the gland the chyle flows onward in lacteals in the mesentery till it is poured into the receptacle for the chyle—**receptaculum chyli** (2, fig. 54). This receptacle is a sac-like expansion at the lower end of a duct—the **thoracic duct** (1, fig. 54). Not only do all the lacteal vessels pour their contents into the receptacle, but other vessels—lymphatic vessels of the lower limbs, to be described immediately—also join it. It lies on the front of the spinal column at the level of the upper lumbar vertebræ (p. 45). From the receptaculum chyli the thoracic duct passes upwards along the front of the spine through the cavity of the chest to the root of the neck. Here it curves forwards and joins a large vein from the neck—the internal jugular—just where that vein joins a large one from the arm (3, fig. 54). So that the chyle, after passing through the mesenteric glands, is carried up to the root of the neck by the duct, and there poured into the blood. The thoracic duct is

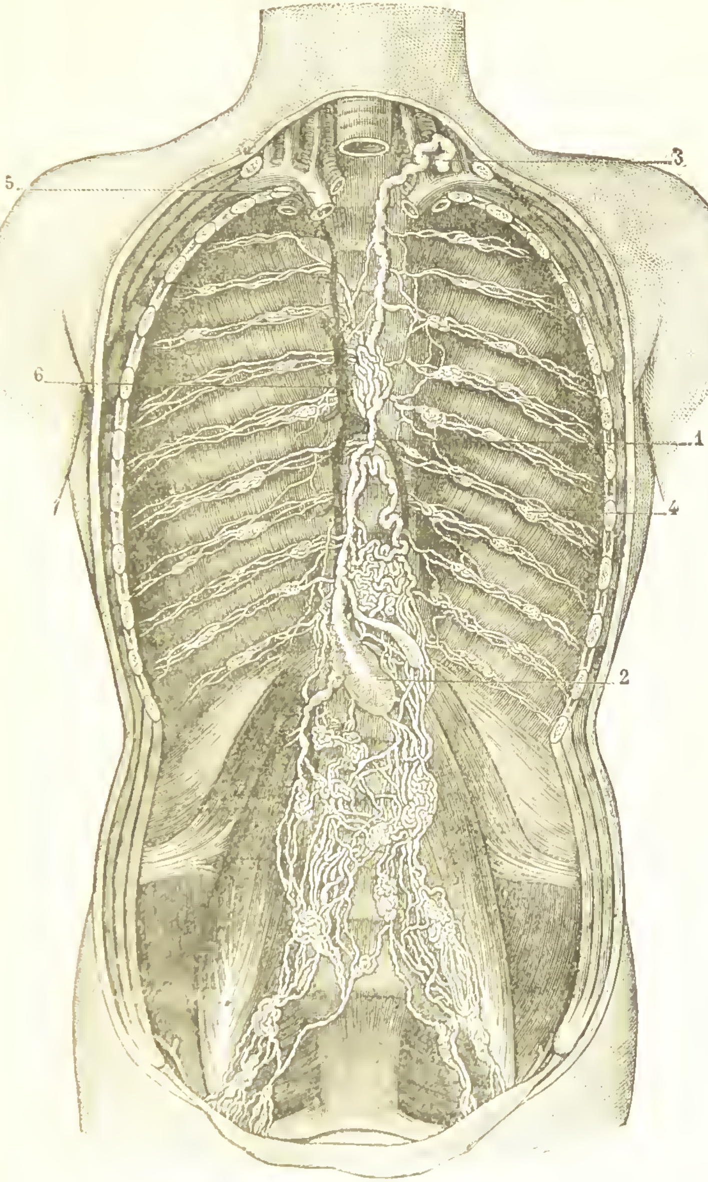

Fig. 54.—The Thoracic Duct and Lymphatic Vessels.

from 15 to 18 inches long, and about the diameter of a small crow-quill.

In the course of the lacteal vessels and thoracic duct there are valves which direct the flow of fluid and prevent it passing backwards, while a valve at the junction of the duct and the veins in the neck permits the contents of the thoracic duct to flow into the vein, but prevents the blood passing from the vein into the duct.

Fig. 54 shows the course of the thoracic duct. Lymphatic vessels are seen joining it from below, and from the walls of the chest. Glands are shown in the course of the vessel, 4 pointing to a gland of the chest wall. 5 and 6 point to veins.

Now in every organ and tissue there is a set of vessels, called **lymphatic vessels**, precisely similar to the lacteal vessels of the mesentery; and they are connected with lymphatic glands just as the lacteals are connected with mesenteric glands. These lymphatic vessels contain a fluid called **lymph.** What lymph is must be properly understood. The blood flows through the whole body, being distributed in small vessels with extremely thin walls. As the blood flows in these fine vessels through a muscle, for example, it oozes through the delicate walls, so that the fibres of the muscle are bathed in the fluid, and the muscle can select the nourishment which it requires, just as a river flowing through a large plain may be made to water the whole of it, by a set of channels being cut here and there throughout it, along which the water may be caused to flow, and be thus brought near every part of the fields. It is the presence of lymph among the tissues that gives to them their softness and moisture. More fluid escapes from the blood-vessels than may be necessary for the nourishment of the tissues. The excess must be removed. It passes into the lymphatic vessels which abound in muscle. Since the fluid has bathed the tissue, it will have picked up materials from the muscle, principally waste substances which have been produced by muscular work. This excess of nourishment, along with the waste substance removed with it from the tissues, forms lymph. The lymph is not cast out of the body; it is returned to the blood. But even as the chyle from the intestine was not in a fit condition for immediately joining the blood-stream, and was passed through the mesenteric glands to be properly worked up, so the lymph is carried to lymphatic glands, where it undergoes certain processes to fit it for being poured into the blood. Here, then, is another example of the marked economy exhibited in the body. Nothing is cast out in the ordinary healthy body that can be of further service in the system. As to the characters of lymph, they resemble those of chyle. It is a turbid fluid, slightly yellowish, clots readily, and contains white cells, like the white cells of the blood, but it does not contain the minute globules of fat that abound in chyle.

It has been said that lymphatic channels exist in every organ and tissue of the body; and perhaps it will give some idea of their abundance when it is said that it has been estimated that the quantity of fluid picked up from the tissues by their agency and restored to the circulation in 24 hours is equal to the bulk of all the blood in the body. The lymphatic vessels unite to form larger and larger vessels, and in the end join the thoracic duct, with the exception of the lymphatics of the right side of the head and chest and right arm. These latter form a short wide trunk—the **right lymphatic duct**—which opens into the junction of the jugular vein of the right side, coming from the head, with the vein coming from the right arm, a similar position to that of the thoracic duct on the left side. In fig. 54, 5 points to the vein formed by the junction of the veins of the head and arm. Thus all the lymphatic vessels of the lower limbs, of the abdomen, of the left arm, and of the left side of the head and chest, and all the lacteal vessels from the intestine, pour their contents into the thoracic duct, while the lymphatics of the rest of the body join the right lymphatic duct.

The following cuts have been introduced to give an idea of the large number of lymphatic vessels and glands in the body, and of their positions. They represent only the glands and vessels found just beneath the skin.

Fig. 55.—Lymphatic Glands of Head and Neck.

Glands in front of and below the ear, *a*, *b*, under the jaw, *b'*, under the chin, *c*, behind the ear, *e*, *f*, at the back of the head, *d*, in the neck and above the collar-bone, *g*, *h*, *i*, *k*, *m*, on the chest, *n*. The dark lines are communicating lymphatic vessels.

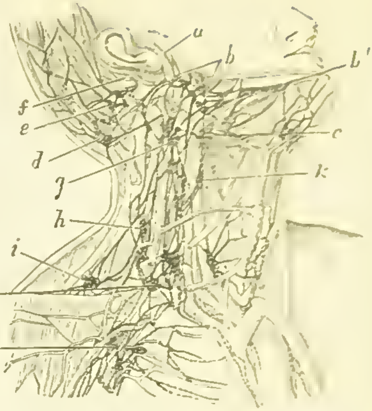

Fig. 55.

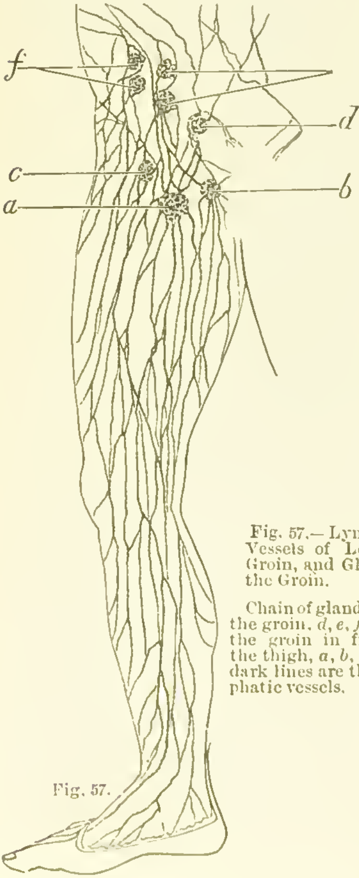

Fig. 57.

Fig. 57.—Lymphatic Vessels of Leg and Groin, and Glands of the Groin.

Chain of glands above the groin, *d*, *e*, *f*, below the groin in front of the thigh, *a*, *b*, *c*. The dark lines are the lymphatic vessels.

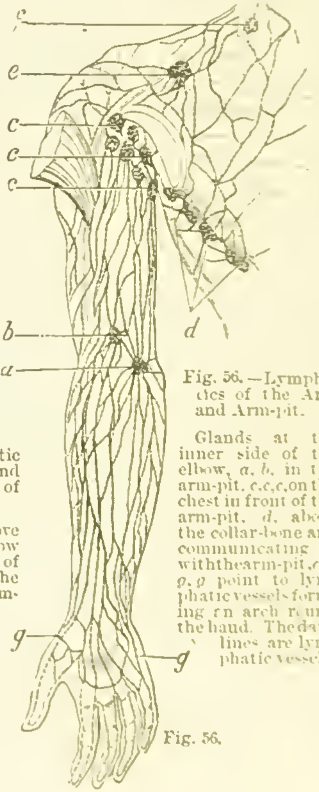

Fig. 56.

Fig. 56.—Lymphatics of the Arm and Arm-pit.

Glands at the inner side of the elbow, *a*, *b*, in the arm-pit, *c*, *c*, *c*, on the chest in front of the arm-pit, *d*, above the collar-bone and communicating with the arm-pit, *e*, *f*. *g*, *g* point to lymphatic vessels forming an arch round the hand. The dark lines are lymphatic vessels.

Advantage is taken of the absorbing power of the lymphatics to introduce medicines into the system. When ointment is rubbed into the skin, it is no doubt by means of the absorbent vessels that part of it is picked up and carried into the blood. The skin of some animals absorbs very readily, that of man not so readily. Still, experiment has shown that a person placed in a bath will absorb some water by the skin, and, if carefully weighed, he will be found heavier on leaving the bath than before entering it. Efforts have been made to nourish persons, who could not take food by the mouth, by means of milk baths, &c., though, from the comparatively small amount taken up, the success has not been great. Another method of administering medicines depends on the absorbing power of the skin and tissues beneath it, the method of *hypodermic* injection (Greek *hupo*, under, and *derma*, the skin). It consists in thrusting the point of a hollow needle under the skin. The needle is connected with a small syringe containing a drug in solution. When the piston of the syringe is pushed down, the fluid is forced along the hollow needle into the tissues under the skin, from which it is rapidly sucked up by the absorbent vessels and passed into the blood. Solutions of morphia are given in this way for the relief of pain. The speed of absorption is shown by the fact that within two or three minutes, sometimes indeed within a few seconds, after the injection, the pain in many cases vanishes. Again, every smoker knows that if he draws the smoke of tobacco into his lungs, he will speedily feel its effects in his head. The moist membrane of the lungs has seized upon the vapour, and its elements have been absorbed by the lymphatics, and, reaching the brain by the blood, have produced their characteristic effects. Absorption by the bowels, absorption by the skin, and absorption by the lungs are thus facts of very great importance in the body. Let it be remembered that in each case the materials sucked up are passed through glands to be worked up into a fit state for entering the blood.

Blood Glands.

Along with the lymphatic glands there is classified a number of organs called **blood glands,** because, like the lymphatic glands they are supposed to have something to do in preparing material for the blood. They are also called **ductless glands,** because, though apparently organs for preparing materials to be of use in the body, they have no ducts or canals along which any material they may prepare may be conveyed away.

The **Spleen** is the chief of these. It is situated in the abdomen to the left side of the stomach in the hypochondriac region (p. 73). Its position in reference to the stomach is well shown in fig. 51, and by studying this figure in conjunction with fig. 46, a good idea may be obtained of its position in reference to the rest of the body. The spleen is popularly called the "melt." It weighs usually from 5 to 7 ounces, is an elongated, flattened body, 4 to 5 inches in length, and 3 inches broad. It is usually of a deep red or a purplish colour. It is a gland of considerable importance, if we are to judge of its blood supply, for it receives an artery—the **splenic artery**—directly from the aorta, the chief blood-vessel of the body.

Its vein—the **splenic vein**—joins the portal vein, as we have already noted on p. 106. Its structure much resembles that of a lymphatic gland, already described. It has a fibrous capsule, from which partitions, or *trabeculæ*, pass inwards, dividing off the organ into spaces by the irregular net-work they form. In these spaces is inclosed spleen pulp, which consists of adenoid tissue (p. 125), rich in cells of various sizes, like the white corpuscles of the blood. If a spleen be cut open and looked at with the naked eye, small white round bodies, like sago grains, are seen scattered through it. These are the **corpuscles of the spleen** or the **Malpighian bodies of the spleen.** They are masses of quite similar tissue to that of spleen pulp, consisting of white cells in a net-work of fine fibres, and through each body passes a branch of the splenic artery. Fig. 58 shows a branch of the splenic artery (*a*), with the corpuscles (*c*) situated on its twigs (*b*). The blood passes from the capillaries of the artery into fine spaces among the spleen pulp, from these to larger spaces, and then on to the veins, which carry it away from the organ. In fact the spaces are of such a character that the blood from the artery filters through the pulp, just as fluid would pass through a sponge, and is then collected by the veins.

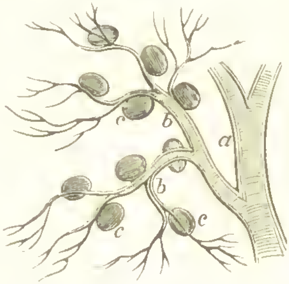

Fig. 58.—Portion of Splenic Artery, with Corpuscles of the Spleen attached to its twigs.

Functions of the Spleen.—Such a remarkable structure suggests that the business of the spleen is to affect in some way the quality of the blood. As the blood filters through the spongy pulp, it may be that some important change is wrought in it by the active cells of the pulp, either, as some hold, in the way of removing from the blood-current old and worked-out red cells, or, as others believe, in the direction of adding to the blood new and active white cells, for the white cells of the spleen are not distinguishable from those of the blood. The blood coming from the spleen is said to be richer in white cells and poorer in red ones. It has been found that the spleen increases in size after a meal, being considerably swollen five hours after a meal, remaining so for some time, and then returning to its usual size. So that it undergoes a regular alternate expansion and diminution in size. When, however, it is mentioned that the spleen has been wholly removed from an animal without any apparent effect, it will be understood how vague and obscure is yet the question of its function. An old view, not now maintained, was that the spleen acted as a sort of overflow reservoir to the liver, so that, when the liver became engorged, the spleen received an extra quantity of blood, distended readily owing to its spongy nature, and thus acted as a sort of safety-valve to the liver when any temporary obstruction to the passage of blood, through the portal vein, threatened danger to that organ.

In ague and other malarial diseases the spleen becomes remarkably enlarged.

The **Thyroid Gland** is another of the ductless or blood glands. It is situated in the neck, and consists of two lobes or divisions, one on each side of the box of the windpipe, the two being connected by a cross-piece. It is usually larger in the female than in the male. Its position may be seen by reference to fig. 61 on p. 149. It consists of a capsule, sending in partitions which divide off the gland into spaces, occupied by round or oval sacs or vesicles, which are lined with cells and filled with glairy contents. The gland is richly supplied with blood-vessels. It is supposed, like the spleen, to have something to do with the destruction of worn-out blood corpuscles; at any rate, in some way it modifies the quality of the blood. It undergoes great enlargement in **goitre** (*Derbyshire neck*), and a peculiar form of idiocy, called **cretinism,** is associated with this disease.

The **Thymus Gland** also belongs to the blood glands. It also is placed on the windpipe, but lower down than the thyroid, being in the upper part of the chest, behind the top of the breast-bone. It is in its period of greatest activity before birth, beginning to degenerate soon after birth. Gradually the greater part of the gland disappears, its place being taken by connective tissue and fat, so that with the end of childhood little of it remains. It consists, like the lymphatic gland, of spaces inclosing adenoid tissue (p. 125). It is supposed to have to do with the elaboration of the blood, but nothing definite is known of its functions.

The **Supra-renal Capsules** are two small bodies connected with the kidneys. They are in shape not unlike a cocked hat, and one surmounts each kidney. They are large before birth. In structure they are peculiar. The fibrous investment of the gland gives off divisions, which pass inwards, dividing it off into spaces, some of which are circular, some oval, and some small and irregular. These spaces are filled with masses of large epithelioid cells. The blood-vessels ramifying between the groups of cells are very numerous, as also are the nerves. Of their function nothing quite definite is known.

Peyer's Glands have been already mentioned as occurring in the mucous membrane of the intestine (p. 105). They are small round, shut sacs, composed of a fibrous tissue capsule, and containing the same sort of tissue as the lymphatic gland. They are affected in typhoid fever. Because of their resemblance in structure, they are classed with the blood glands, nothing being known of their functions.

The Tonsils (p. 95) exhibit an identical structure.

There used to be classified with the blood glands two bodies, cellular in structure, the **pituitary** and **pineal** bodies. Both are situated in the brain, one in the floor and the other in the roof of the third ventricle (p. 258). Recent researches have shown some relationship between the pituitary body and the thyroid; and it seems that the pineal body is the remains of a developmental stage. The pituitary body is called from *pituita*, Latin for phlegm, because it was supposed by the ancients to discharge phlegm down the nostrils. The pineal gland is about the size of a cherry-stone, and is called from *pinea*, a pine.

Chapter VII.

THE BLOOD AND ITS CIRCULATION.

In Chapter V. we discussed the process of digestion, and perceived that the whole end and aim of that process was to prepare material for entering the blood to maintain its quality and quantity. The consideration of the lymphatics and blood glands, in Chapter VI., showed that the blood receives supplies from lymphatic vessels of lymph prepared by lymphatic glands, and had also additions made to it by the blood glands, notably the spleen. We thus perceive that the blood, which is being continually drained by the demands made on it by the whole body for its nourishing material, has two main sources of supply, namely, first and chiefly, the food, and secondly, the lymphatics and blood glands. We shall see in the succeeding section that this does not exhaust the sources whence the blood draws supplies, and that the lungs are the channel by which a substance is conveyed to the blood, not second in importance to what is received by the alimentary canal, the substance **oxygen gas**, namely.

Such being the sources of the blood, our next question is as to its nature.

The Microscopic Appearance of Blood.—The microscope reveals much as to the nature of the blood. Under a moderately high magnifying power the appearance of a drop of blood is as represented in fig. 59. The blood is evidently not altogether fluid. It contains small bodies in great numbers, which are floating in a liquid. Contrary to what would be expected, the liquid is of a light straw colour, indeed almost colourless. The small bodies, however, are coloured. They appear red when seen in layers, but singly they are yellow. The fluid is called **plasma,** or **liquor sanguinis** (liquid of the blood); the small bodies are the **red corpuscles** (small body, Latin *corpus*, a body) or cells of the blood. If the preparation be quickly examined, or if the cover glass be gently disturbed with a needle, the corpuscles will be seen separate from one another, but they quickly run together to form rows or rouleaux, like piles of coin, as represented in the figure. This is owing to their shape. If one be carefully examined as it lies on its edge, it presents the appearance shown at *a* in fig. 59, thinner at the middle than at either end. If one be seen lying on its face its appearance is as represented by *b* of the same figure. It is circular, and the centre is dark, while the circumference is clear. If the focus of the microscope be altered, the centre becomes clear and the circumference dark. In other words the two surfaces of the corpuscle are not flat, they are hollowed towards the centre, so that the corpuscle is thinner at the centre than at the circumference. The body is thus concave on each surface, is, in a word, a biconcave disc. On a casual glance the red corpuscles are the only bodies seen in the fluid, but, on looking carefully, other bodies slightly larger and few in number are perceived. They are seen here and there in the spaces formed by the rows of red cells. They keep separate from one another, are white, and contain little dark granules in their interior. They are the **white or colourless corpuscles** of the blood, and are also termed **leucocytes** (Greek *leukos*, white, and *kutos*, a cell). They are represented in fig. 59. *c*. There are usually not more than three or four seen in the field. There is in healthy human blood, on an average, one white blood corpuscle for every 600 to 1200 red ones. They are irregularly spherical in shape.

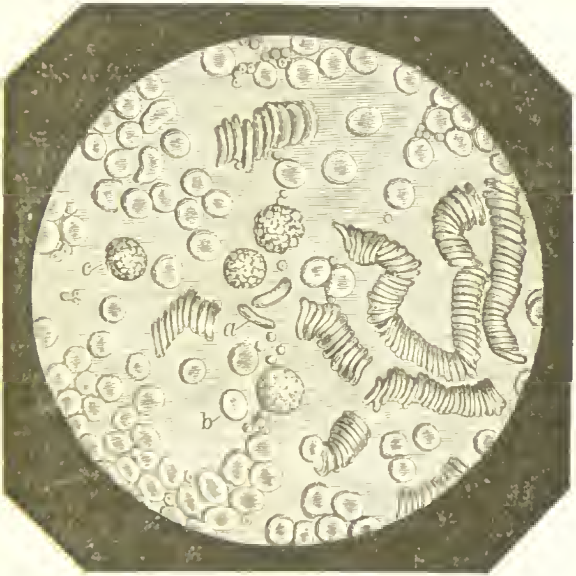

Fig. 59.—A Drop of Blood, seen under a Microscope magnifying by 350 diameters.

Much can be learned about these blood cells by simple means. On the addition of water to the drop of blood, the red corpuscles swell up, lose their biconcave shape, and become round. They also become paler, while the fluid in which they float becomes yellowish. The meaning of this change is that the water has entered into the corpuscle, swelling it up, and has dissolved some of its colouring matter, which passes out and stains the plasma. The action of acetic acid causes the red blood corpuscle to disappear. It becomes paler and paler, and finally becomes invisible, or at least but the faintest shadowy indication of it is left, if the action of the acetic acid is not pushed. No trace of it may be left. On white blood corpuscles the action is similar, the cell becomes more and more transparent, till the bulk of the granular protoplasm of which it is composed disappears. Something else is, however, brought into view, namely, small bodies—*nuclei*—contained in the cell, but not easily seen, because obscured by the protoplasm, till the clearing up of the cell reveals them. A small white blood corpuscle may contain only one nucleus, the larger ones contain several. Thus, besides the differences already noticed, the red and white corpuscles of human blood differ in this, that the latter are nucleated while the former contain no nucleus.

Almost all vertebrate animals (animals having a backbone) have the kinds of blood cells described, but they are not all of the same appearance as in human blood. In mammals (animals that suckle their young) the red cells are disc-shaped and without a nucleus, except in the camel, where they are oval though without a nucleus. In all other vertebrate animals they are oval and have a nucleus. In man and in all mammals, with the exception of the camel tribe, the red corpuscles are biconcave as already described; but in birds, reptiles, and fishes they are biconvex, thicker in the middle than at the circumference. They differ in size also in various animals.

When carefully measured, human red blood corpuscles are found to be about the $\frac{1}{3200}$ of an inch across. The white corpuscles are larger, being about the $\frac{1}{2500}$ of an inch in diameter.] In the elephant they are $\frac{1}{2745}$ of an inch; in the musk deer they are very small—$\frac{1}{12325}$. In the proteus, a remarkable amphibian (an amphibian illustrates both ordinary pulmonary breathing and also respiration by means of gills, like the fish)—in the proteus there are the largest red corpuscles found in any vertebrate animal —$\frac{1}{400}$ of an inch. In fig. 60 are shown corpuscles of various animals magnified by the same amount.

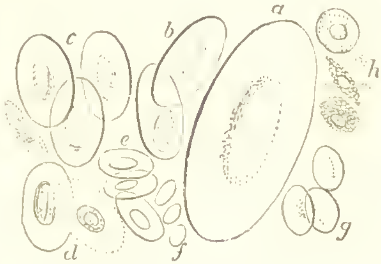

Fig. 60.—Blood Corpuscles of various animals magnified on the same scale.

a, From proteus (an amphibian); *b*, salamander (amphibian); *c*, frog; *d*, frog's corpuscle after addition of weak acetic acid, showing nucleus; *e*, bird; *f*, camel, oval, but not nucleated; *g*, fish; *h*, crab or other invertebrate animal.

A remarkable thing about the colourless blood corpuscles is their power of altering their shape. The red corpuscle can have its shape altered, but only by pressure from without. The pressure of one on the other changes the shape, and on removal of the pressure the old shape returns. If a red corpuscle is passing through a narrow channel it lengthens and becomes narrow till it has passed through, when its shape is restored. But the white corpuscle is active in its change. This change, though constant, is so slow as to be with difficulty noticed in an ordinary preparation of a drop of blood. The change of shape is effected by what is called *amœboid* movements, because the movements are similar to those of the *amœba* (p. 27), a minute organism found in stagnant pools. The corpuscle can push out and draw in portions of its body, which is now globular and now elongated. By such changes of form the cell may wander from place to place. Recent observations have shown that the white corpuscles may wander out of the blood-vessels in the living body, pushing their way through the living walls and insinuating themselves amongst the tissues outside the vessels. The cells have been called, in consequence, *wander cells*. The white cells found in lymph after it has passed through a lymphatic gland, found also in such numbers in lymphatic glands and in the spleen, are identical with those of the blood. It is supposed that they take their origin in the spleen and lymphatic glands, and that the red corpuscles are afterwards developed from them. The number of white cells increases in the blood after meals and quickly diminishes again. Thus a German observer estimated the proportion of white cells to red before breakfast as 1 to 1800, an hour after breakfast as 1 to 700, and some hours later as 1 to 1500.

The **Quantity of Blood** in the body has been estimated in various ways, though, of course, the quantity cannot be stated with absolute accuracy. It is supposed in an adult man to be about one-thirteenth of the total weight of the body, that is about twelve pounds by weight in a person of eleven stones.[1] When the multitude of corpuscles in a single drop of blood is considered, it will be evident that the total number of corpuscles in the blood of the body is scarcely countable, and certainly quite inconceivable. They have been counted, however, and the estimate is that in the $\frac{1}{625}$ of a cubic inch of blood there are a little over five millions of corpuscles. It has also been estimated that if all the red blood corpuscles in the blood of an adult man could be laid down side by side, they would cover an area of 3000 square yards.

Coagulation of the Blood.—If blood be drawn from an animal into a vessel surrounded by a freezing-mixture it remains liquid. The corpuscles, being heavier than the fluid in which they float, fall to the bottom, and thus the blood is separated into the corpuscles at the bottom of the vessel, and the plasma or liquor sanguinis above. If the blood were kept in the fluid state for a sufficient time the difference in the layers of plasma and corpuscles would be marked by the great difference in colour, the plasma being almost colourless, and the layer of corpuscles of a deep red. If, then, the cold were withdrawn the blood would speedily cease to be fluid, and would become a coagulated or clotted mass, the solidified plasma having the appearance of a clear jelly with a yellowish tinge. The cause of the clotting is easily seen if one takes a drop of blood on a slide, and waits for a minute or two before putting on a cover glass and examining it. In two or three minutes the drop of blood on the slide forms a clot. On covering it with a covering glass, and examining with the microscope, fine glassy fibres are seen forming an irregular net-work, in the meshes of which lie the corpuscles. It is the formation of these fibres that has caused the setting of the drop of blood. The substance thus formed from blood, after it is withdrawn from the vessels, is called **fibrin.** It consists of white, structureless filaments or threads. It does not seem to exist in the blood as fibrin, as we shall see, but is formed after the blood is drawn, or after contact of the blood with foreign bodies. Fibrin is formed very quickly in blood removed from the blood-vessels, but its formation may be delayed by cold, as we have already seen, or by the addition to the blood of certain salts, common salt, for example. Fibrin may be quickly separated from blood by whipping the blood with twigs. The fibrin forms on the twigs, from which it can be washed off, when it appears as a white stringy substance. The fluid remaining after the separation of the fibrin will not coagulate.

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[1] **Distribution of Blood.**—During life about ¼th of the blood is usually present in the liver, ¼th in the voluntary muscles, ¼th in the heart, lungs, and great vessels, and the remaining ¼th in the rest of the organs and tissues.

Suppose now that blood be drawn into a tall glass vessel, no precautions as to the maintenance of a low temperature being taken, in from five to ten minutes coagulation takes place throughout, and a sort of firm red jelly is formed. The corpuscles, not having time to sink to the bottom, are entangled in the meshes of the fibrin, and the whole mass is red in colour. The clot takes the shape of the vessel in which it is contained. If a little delay has taken place in coagulation the corpuscles have sunk to some extent, and the clot will have a deeper colour towards the deeper parts, the bottom layer being deepest of all. The white blood corpuscles are, however, lighter than the red. They do not sink so fast, and are, therefore, entangled nearer the surface of the clot, giving it a whitish or creamy look on the top. This used to be called the **buffy coat**. Where the coagulation has been very quick, the separation has no time to be effected, and the buffy coat is absent. If the clot be left alone in the glass vessel, by and by other changes take place. The fibrin, whose formation has caused the coagulation, begins to shrink. As the clot is attached to the sides of the vessel the shrinking is more pronounced towards the centre, and thus the surface of the clot gets hollowed or **cupped**, as it is called. The shrinking of the clot squeezes out a clear yellowish fluid, which soon separates the clot from the sides of the vessel, and thus we have the clot floating in a fluid of a straw-yellow colour. This straw-yellow fluid is **serum**. Now, let us distinguish between serum and plasma. In blood as drawn from an animal we have corpuscles and plasma or liquor sanguinis. By coagulation the plasma is separated into fibrin and a fluid—the serum. Thus blood, less its corpuscles, is plasma or liquor sanguinis; and plasma, less its fibrin, is serum. This difference may be represented in the following way:—

Circulating Blood consists of—			Coagulated Blood consists of—
Liquor Sanguinis or Plasma	=	Serum	Serum
		Fibrin-forming substance	Clot
Corpuscles (red and white)			Clot

It was formerly supposed that the fluid part of the blood held fibrin in solution, and that, when coagulation took place, the fibrin was precipitated or became solid, as in well-known chemical reactions, or that it became solid in consequence of something escaping from the blood, which held it in solution. The view now held is that fibrin does not exist as such in the blood, but is formed, at the time of coagulation, from a substance, called **fibrin-**

ogen, previously in solution in that fluid, the formation being due to the action of a ferment. Why this substance does not form in the blood in the vessels of a living animal has not yet been satisfactorily determined. In certain diseased conditions, however, it is formed. Thus foreign bodies introduced into the current of the circulation—a thread drawn through a blood-vessel and left there, for example—soon become covered with a layer of fibrin. It is well known, also, that a deposit of fibrin may readily occur on a part of the surface of a blood-vessel, or of the valves of the heart, that has been roughened by inflammation. The risk attending such an occurrence is great, and it is specially so when the deposit is on the edges of one of the valves of the heart, for a part of the clot may be detached and whirled away in the current of blood till a vessel is reached too small to give it passage. The clot blocks the vessel, and thus the area which it supplied with blood is either permanently or temporarily deprived of its supply.

It is by the formation of a clot that bleeding from a vessel that has been opened is stopped naturally. The clot closes the opening, and gradually fibrous tissue becomes formed at that part of the vessel, which thus becomes permanently closed. When a wounded artery is tied the same thing happens. A clot forms at the tied part, and finally fibrous tissue takes its place and the vessel is completely sealed up.

The Chemical Constitution of the Blood.—Human blood has an average specific gravity of 1055; it has an alkaline reaction, which in shed blood quickly diminishes up to the moment of clotting. We have seen that circulating blood consists of corpuscles (red and white) floating in plasma. Of the total weight of blood more than one-third, and less than one-half, is made up of the corpuscles, and the rest of the weight is made up of plasma. The plasma contains fibrin-forming substance and serum, the fibrin forming about ·2 per cent, a remarkably small quantity considering the part it plays in coagulation.

The red **corpuscles** consist of 57 parts of water and 43 parts of solid matters in 100 parts of the wet corpuscles. The solid matter is mainly a substance called **hæmoglobin**, forming 90 per cent of the solids of the corpuscles, the remainder being proteid substances, traces of other organic substances (cholesterin and lecithin), and inorganic salts—the salts of potassium and phosphates. Hæmoglobin consists of an albuminous body, **globulin**, and a colouring matter, **hæmatin**, and it is capable of crystallizing in various shapes. It is remarkable for containing 4 parts of iron in 1000. Hæmoglobin forms a combination with oxygen gas called **oxy-hæmoglobin**, which is of a bright scarlet colour. But the oxygen may be removed from the hæmoglobin, which then becomes of a darker and more purple hue; or, if carbonic acid gas be substituted for the oxygen, a dark colour is produced. This is the essence of the explanation offered for the difference between the scarlet blood found flowing in arteries, and the more purplish blood of the veins. This is explained at greater length in Chapter VIII. If hæmoglobin, dark in hue because it has been deprived of oxygen, be exposed to an atmosphere containing that gas, it seizes upon it greedily, and speedily becomes of a bright hue. This is the reason why blood which may have been dark when shed, becomes of a bright scarlet colour, at least on the surface, if exposed to the air. It seizes on the oxygen of the air. Thus the red blood corpuscles consist mainly of a substance greedy for oxygen, and thus these bodies become the oxygen carriers of the body, seizing upon the oxygen which they get in the air in the lungs, and hurrying with it to the remotest parts of the body. Hæmoglobin, it may be added, is also called **hæmatoglobin** or **hæmatocrystallin**.

The serum of blood, that is, the plasma deprived of its fibrin, consists of water 90 per cent, albuminous or proteid substances 8 to 9 per cent, and 1 to 2 per cent of fats and saline matters, and substances capable of being dissolved out by alcohol or ether, and hence called extractives, such as urea, kreatin, sugar, lactic acid, &c. The saline matters are chiefly salts of sodium. Thus the serum differs from the corpuscles in which the potash salts are found.

The blood also contains gases, which may be separated from it by allowing the blood to flow into a vacuum at a temperature higher than blood heat (98°·4 Fahr.). At the ordinary pressure of the atmosphere, 30 inches of mercury, and a temperature of 32° Fahr., the quantity of gas separated from 100 volumes of blood is about 60 volumes. It consists of oxygen, carbonic acid, and nitrogen, in different proportions according to whether the blood was arterial or venous. Thus the 60 volumes are distributed as follows:—

	Of Oxygen	Of Carbonic Acid	Of Nitrogen
In arterial blood, -	20 volumes	39 volumes	1 to 2 volumes.
In venous blood, -	8 to 12 „	46 „	1 to 2 „

The significance of these figures will be commented on at greater length in the section in which breathing and its purposes are discussed (Chapter VIII.); but it is well to note now that arterial blood contains more oxygen and less carbonic acid gas than venous blood. With that fact we at once associate the bright scarlet hue of arterial blood, and the purplish colour of venous blood, remembering the love of the hæmoglobin of the red blood corpuscles for oxygen, and the bright colour resulting from its satisfaction, and the dark colour resulting from deprivation.

The **Functions of the Blood** are to carry nourishment to every tissue and organ of the body. It may be compared to a stream flowing through a tract of country, and giving off branches in all directions, so that it waters every quarter of the district. We know that that tract of country is likely to be extremely fertile, and we know what a change would come over it if the river were dried up; or, if one branch only were suddenly cut off, we know what a contrast the part formerly supplied by that branch would present to the rest, still watered as before. Now for the tract of country substitute the human body, and for the stream, with its many branches to every part of the country, substitute the blood carried in channels (the blood-vessels) to every portion of the body, and we have a very striking similarity. For the blood flowing through a part of the body as surely bathes the tissues beside which it flows, as does a river water the fields along its banks. Thus the liver cells (p. 99) are situated in groups on the blood channels, which exist in such abundance in the liver. As the stream of blood flows past, they select from it what they need for their work, just as different trees and plants along the bank of a stream will suck up what nourishment they need. The liver cells select from the blood the substances out of which they may manufacture the bile salts, the bile pigments, &c. It is the same blood that flows through the brain, and here it comes in contact with brain cells, whose function, connected with thinking, feeling, willing, &c., is very different from that of the liver cells. Nevertheless from the same blood they find nourishment for their life and the source of their activities. They too select from it the substances they need, and convert them into that which it is their business to produce, and which is something very different from bile salts and pigments. It is the same blood that flows through a muscle and bathes the muscular fibres. They also find in it the elements that are necessary for restoring exhausted muscle fibres and building up new ones. It is the same blood that flows through the tissues of the eye and maintains in health and power this most wonderful of optical instruments. In short, just as in one garden you may have the lily and the rose near neighbours to strawberry beds and apple-trees, growing from the same earth and having the same rain and sunshine from heaven, yet each one selecting from the common nourishment the elements it needs, and converting them into flower and fruit very different from one another, so the blood in the human body contains nourishment for the liver cell and brain cell, muscular fibre and sentient organ, which each selects as its needs dictate.

While this is the main function of the blood, it serves that other purpose of carrying away, in its current, from the tissues substances, produced by their work, whose removal is necessary for the continuance of the healthy life of the part.

It is, then, quite clear how conditions of the blood speedily affect the whole body. Suppose the blood to be insufficient in quantity. Each tissue and organ gets a supply, but not enough. Its vigour is, therefore, diminished and its efficiency impaired. If the blood be equally distributed, all parts of the body may suffer equally and general symptoms of ill-health, not symptoms pointing out definitely one suffering part, are the result. In some cases one organ may suffer more than another, may get less than its own share of the diminished supply, and alongside of the general symptoms which point out the general condition, are others indicating some organ on which the privation is specially hard. The blood may, however, be sufficient in quantity but bad in quality. Some particular element may be wanting. For example, scurvy is held to be due to absence from the food of some element, perhaps potash salts, perhaps citric acid, which fresh vegetables supply. Some substance may be present that ought not. For example, the liver may have failed to separate bile, and substances are left in the blood which, being carried through the body, act directly or indirectly as a poison. Some material may also gain entrance by the food, or air, or in other ways, which vitiates the quality of the blood and impairs its value as a nourishing fluid. How dependent, therefore, the whole body is on the quantity and quality of the blood is evident.

THE APPARATUS OF THE CIRCULATION.

The blood being the source of nourishment of all the tissues of the body, its need of constant renewal is apparent, for, otherwise, all nourishing material would speedily be abstracted from it. Moreover tissues not only remove from the blood what they require, but they pour into it the waste products of their activity. If the blood were stagnant in the tissues it would thus not only be deprived of all nourishment, but would be loaded with waste and poisonous material. Therefore, as fresh blood must come constantly streaming to an organ or tissue, so must the stream as constantly flow away again, carrying impurities with it. The main idea of the circulation is thus easy to understand. There must be a central pump, so to speak, from which large pipes, to continue the illustration, pass off, leading to smaller and smaller pipes distributed throughout the whole body. The blood must be pumped into the large pipes and forced along till it reaches the smallest branches, so that it may have access to the remotest parts. There must also be a second system of pipes, by means of which the blood, after nourishing the tissues and being laden with their waste products, is brought back again to the central pump to be again distributed. Somewhere in this circuit there must be means for purifying the blood from the waste products it has received. Now this central pump is the **heart**, and the pipes leading from it and passing into smaller and smaller branches are the **arteries**, the fine vessels into which they ultimately pass being called the **capillaries**, while the pipes along which the blood is brought back to the heart are the **veins**. Of course there can be no break in the continuity between arteries and veins. The arteries, beginning large at the heart, become smaller and more numerous till they end in the fine, hair-like capillaries; and then the reverse process must go on, the blood passing, on its return journey, from smaller to larger vessels, till the large veins are reached which open into the heart. So that the arteries *end* in the tissues in exceedingly fine vessels—capillaries, and the veins *begin* in the tissues in exceedingly fine vessels—capillaries, and they must be mutually continuous, so that the capillaries of the arteries pass insensibly into capillaries of veins. Heart, arteries, capillaries, and veins form the apparatus of the circulation, and we must understand the apparatus before we proceed to examine the process of the circulation itself.

The Heart.

The **Heart** is a hollow organ made of muscle, whose fibres, being striated, resemble, in this respect, those of voluntary muscle, described on p. 59, but differ from them in being beyond the control of the will, that is, involuntary. It is situated in the chest, between the right and left lungs, which partly cover it. Fig. 61 shows its position.

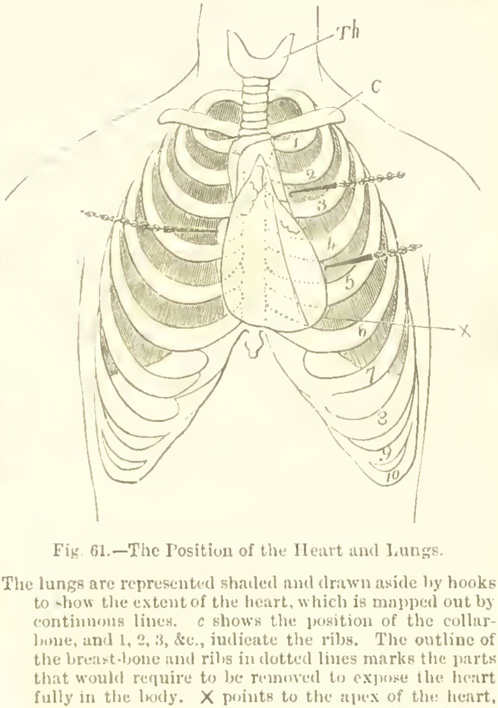

Fig. 61.—The Position of the Heart and Lungs.

The lungs are represented shaded and drawn aside by hooks to show the extent of the heart, which is mapped out by continuous lines. *c* shows the position of the collar-bone, and 1, 2, 3, &c., indicate the ribs. The outline of the breast-bone and ribs in dotted lines marks the parts that would require to be removed to expose the heart fully in the body. X points to the apex of the heart, occupying a position between the fifth and sixth ribs. *Th.* is the thyroid gland referred to on page 126.

In **shape** the heart resembles a cone, the base of which is directed upwards. It lies, however, obliquely in the chest, so that the base is not only directed upwards, but also backwards and to the right side, while the apex of the cone is downwards, forwards, and to the left side. The heart lies more to the left than to the right, but, as may be seen from the figure, it yet extends slightly beyond the middle line to the right. When the lungs are fully expanded only a small part of the front of the heart is exposed. One may easily map out on the chest of a healthy man the position occupied by the heart. Let a straight line be drawn, in ink, across the chest on a level with the upper border of the cartilage of the third rib (see fig. 23, p. 48), let a second line be drawn across at the level of the junction of the breast-bone and xiphoid cartilage (*q* of fig. 23). These lines indicate the extreme limits which the heart reaches upwards and downwards in health. The extent to which the heart reaches on each side is marked by drawing one vertical line at a distance of 1½ inches to the right of the middle of the breast-bone, and a second vertical line about 3½ inches to the left of the middle of the breast-bone. The position of the apex is obtained by marking the spot where the heart is felt beating against the wall of the chest (× in fig. 61), which is usually about 1 inch below, and a little to the right of, the left nipple in the space between the fifth and sixth ribs. With the aid of this mark, and within the lines, the outline of the heart may be drawn, and thus a good idea obtained of its position.

1½ R
3½ L
1 in V
left N.

The average **size** of the heart is 4¾ inches long, 3½ inches broad, and 2½ inches thick. It is usually smaller in women than in men. It is roughly measured in individuals by the size of the closed fist.

4 3/4
3 ½
2½

The **coats** of the heart. The organ is suspended in the chest by the great vessels connected with it at the base, to be considered later; but it does not hang free. It is surrounded by a membranous bag called the **pericardium.** The bag is really a double one, consisting of two layers, one within the other, the inner one being closely adherent to the heart, and being separated from the outer one by a slight space, in which there is usually a small quantity of serous fluid—the **pericardial fluid.** The fluid permits one surface to glide on the other without friction. The pericardium passes over the roots of the great vessels at the base of the heart, and it is here that the inner layer becomes continuous with the outer layer. A good idea of the pericardium will be obtained if one takes two thin paper bags, of which one is slightly smaller than the other, so that one may be contained within the other, both being fully distended. Now slightly fold back the edge of the mouth of the inner bag and gum it all round to the edge of the mouth of the outer one. There is now made a double bag with an inner and an outer layer, and a small space between them, completely shut off from the outside. Suppose the closed fist to be just large enough to fill the inner bag, it will represent the heart, to which the inner layer of the pericardium is adherent. The wrist will represent the great vessels passing off from the heart, around which the neck of the double bag extends. Part of the pericardium towards the apex is adherent, on the outside, to the diaphragm below—the muscular partition which separates the chest from the belly. The pericardium forms thus an outer coat or covering for the heart. Within it is the proper structure of the heart, the muscular structure, supplied, like all other muscles, with blood-vessels, nerves, lymphatics, &c. The muscular fibres are disposed in several layers, which appear to be spirally arranged with reference to one another. The inner lining membrane of the heart is called the **endocardium**, and is very delicate.

The **chambers** of the heart. It has been said that the heart is a hollow organ, but the cavity is not single. A complete muscular partition divides it into two, so that there is a right and a left side, between which there is no direct communication except in the child before birth. That partition is indicated on the outside of the heart by a groove passing from the base to the apex, along which large blood-vessels run (fig. 62). The partition, as the groove indicates, keeps to the right side of the apex, so that the whole of the apex is, by this division, on the left side. The two cavities thus formed are each divided by a horizontal partition into an upper and a lower chamber. The partitions are not permanent, however, for they consist of flap valves, which, when closed, completely separate the upper and lower chambers, but which are capable of opening so that the chambers become continuous, just as folding doors between two rooms, if closed, make them two separate rooms, but if open, make them practically one room. The heart has thus four chambers, two on each side. Fig. 63 shows them very well. It represents a heart cut open vertically.

From L the vertical partition is seen passing, in a slightly irregular course, to M, and it is plainly shown how the apex is kept to the left. The transverse partition is in the direction from E to G, and the four chambers are marked C, D, A, and B. Now the two upper chambers are called **auricles** (Latin *auricula*, the outer ear), from their supposed external resemblance to the ear (see figs. 62 and 63, C and D). There are, therefore, the right and left auricles. The lower chambers are called **ventricles** (Latin *venter*, the belly), for they form the chief portion of the muscular substance of the organ, and there is a right and a left ventricle (figs. 62 and 63, A and B).

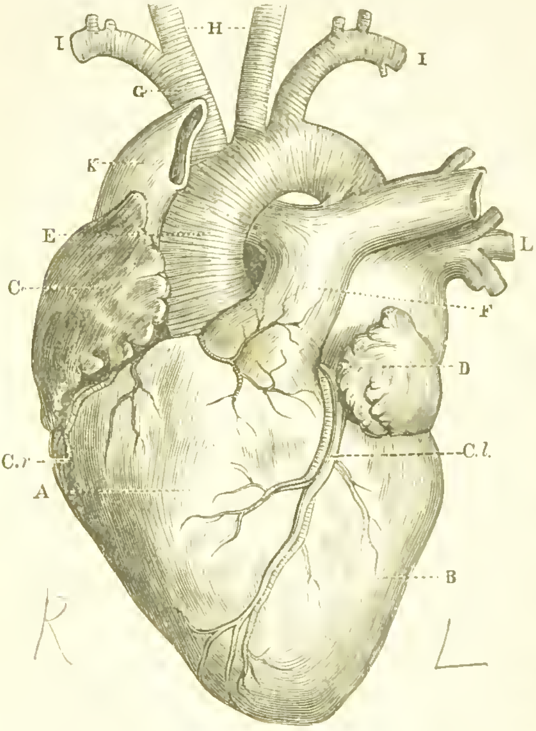

Fig. 62.—The Heart.

A and B, right and left ventricles. C and D, right and left auricles. E, aorta. F, pulmonary artery. G, innominate artery, branch of aorta. H, right and left carotid branches (to head and neck). I, I, subclavian branches (to upper limbs). K, superior vena cava. L, pulmonary veins. C. *r.*, right coronary vessels. C. *l.*, left coronary vessels.

There is a great difference between the walls of the auricles and those of the ventricles, the former being thin and soft, the latter thick and strong and very muscular: especially is the increased thickness evident in the walls of the left ventricle. This difference is connected with the greater amount of work thrown on the ventricles and especially the left, as will be seen when the action of the heart is considered (p. 160).

The **valves** of the heart are most important structures. They consist of folds of the inner lining—endocardium—strengthened by fibres of connective and elastic tissue. One is situated in the constriction between the right auricle and ventricle. It is called the tricuspid valve, because it consists of three cusps or flaps. In fig. 63 E points to one flap. When the flaps are stretched horizontally they completely close the communication between the upper and lower chamber. On the left side the valve in the constriction between left auricle and ventricle consists of only two flaps, and is called the **mitral valve** (fig. 63, F), because of its supposed resemblance to a bishop's mitre. When the valve is closed the flaps meet in the middle line and block the opening between the two chambers. When not stretched horizontally, the flaps of both valves are hanging downwards into the lower chambers, and the passages between the auricles and ventricles are open so that the upper and lower chambers of each side are continuous. The passage on the right side, guarded by the tricuspid valve, is called

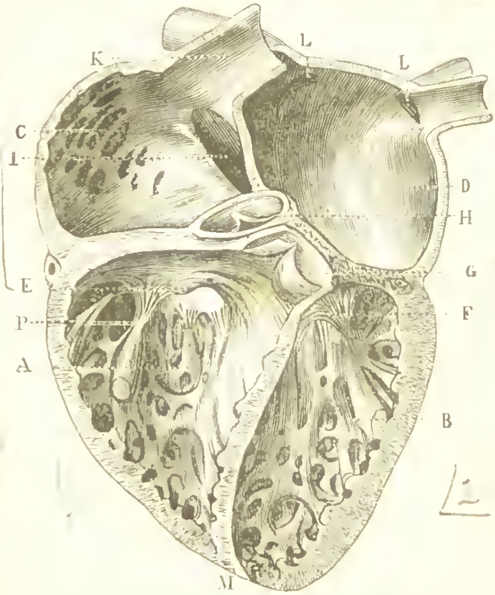

Fig. 63.—The Heart opened to show its Chambers.

A and B, right and left ventricles. C and D, right and left auricles. E, tricuspid, and F, mitral valves. G, pulmonary artery. H, aorta. I, orifice of inferior vena cava. K, superior vena cava. L, L, Orifices of pulmonary veins. M, termination of septum. P, papillary muscle.

the **right auriculo-ventricular opening**, that on the left side, guarded by the mitral valve, is called the left **auriculo-ventricular opening**. From the right ventricle a large vessel passes to the lungs—the **pulmonary artery**, and from the left ventricle a large vessel goes off—the **aorta.** The openings of these vessels into the ventricles are guarded by valves—**semilunar valves.** Each semilunar valve has three flaps, and each flap is half-moon shaped, hence the term semilunar (*semi*, half, and *luna*, the moon). These valves, when shut, cut off the communication, on the right side between the pulmonary artery and the right ventricle, and on the left side between the aorta and the left ventricle. Most cases of heart disease consist of some affection of one or other of these valves; and anything that interferes with their efficient opening or closing may produce most profound changes in every organ of the body, by interfering with the due distribution of blood.

Let us take the right side of the heart and consider it first. Blood, let us suppose, is pouring into the right auricle from veins that join it, bringing blood from all parts of the body. The tricuspid valve is open, its flaps hanging down into the ventricle. The blood, therefore, having entered the upper chamber flows through the opening into the lower chamber, but the auricle, being smaller than the ventricle, fills sooner. As soon as it is full, the muscular walls are stimulated by the pressure of blood on them and contract vigorously. The contraction is accomplished at the expense of the cavity, just as, if an elastic ball be squeezed by the hand, its cavity will be obliterated, and the blood which filled the cavity is driven out. In what direction will it go? It may pass in two directions, either backwards into the veins, from which it has come, or downwards into the ventricle. But the mouths of the veins contract along with the auricle, and, besides, the veins are already full of blood, waiting the relaxation of the auricle to enter it. Thus all the blood will be driven down into the ventricle. The auricle having emptied itself begins to relax, and blood, entering from the veins, begins to fill it again. The ventricle contained already a considerable quantity of blood before the emptying of the auricle into it, and the additional quantity, received on the auricular contraction, just fills it. Its muscular walls are stimulated by the pressure of blood, and thus, as soon as the auricle has discharged its contents into it, the ventricle begins to contract. It contracts with much greater vigour than the upper chamber, because of the increased thickness and power of its walls, and the blood is driven out of it with considerable force. In what direction will it go? It may be forced upwards, back into the auricle, or it may be forced into the pulmonary artery, which passes, as already noted, from the right ventricle to the lungs. Now the tricuspid valve comes into play to determine which of these two directions the blood shall take. The free edges of the flaps are hanging downwards into the ventricle, but the blood is driven by the contraction against them, and forces them up so that the three flaps meet in the middle line and the opening is effectually closed. The action may be roughly illustrated thus: suppose a room filled with people, and the door of the room, which opens only *inwards*, to be standing half open; suppose now a sudden movement of all the people towards the door, at once the door would be pressed on from behind, and would be speedily shut if the people were moving blindly onwards. The blood, therefore, is prevented passing backwards into the auricle. It is urged, then, into the pulmonary artery, which also is provided with valves, but they open away from the ventricle into the artery. The flaps are, consequently, pressed close against the wall of the artery and the passage is quite free. Suppose the room, already thought of, to have a second door, opening *outwards* into a passage; the stream of people pressing against it would drive it widely open so that the people might pass out. The ventricle remains contracted for a measurable period of time and then relaxes. The tricuspid valve, no longer pressed close, opens, partly forced to do so by the weight of blood now pouring into the chamber above it, and blood is again permitted to flow into the ventricle from the auricle. Now what is the purpose of the valves at the entrance to the pulmonary artery? While the ventricle remains contracted the blood, driven out of it, is being forced onwards along the artery to the lungs, but because of the ever-increasing smallness of the branches of the artery the blood encounters some resistance to its flow. As soon as the ventricle begins to relax, the pressure, urging on the blood from behind, is no longer exerted, and so the resistance in front tends to cause a back wave which would drive part of the blood back again into the ventricle. The back wave, however, gets into the pouches of the semilunar valves, forces the three flaps to meet in the middle line, the passage is barred, and the return of any of the blood to the ventricle prevented.

A similar series of occurrences is found to take place on the left side of the heart. The left auricle is filled with blood entering by veins. It contracts and forces the blood through the opening of the mitral valve into the left ventricle. A forcible contraction of the ventricle immediately follows; the blood, pressing against the flaps of the mitral valve, brings them together, thus preventing its passing up again into the auricle. It is forced to flow out into the artery, arising from the ventricle—the aorta—whose valves open widely. As soon as the ventricle begins to relax, there is a tendency for the blood in the artery to recoil because of the resistance to its onward movement; and the back wave, getting into the pouches of the aortic semilunar valves, causes them to close, so that the return of blood to the ventricle is prevented.

Thus the valves determine the direction of the flow of blood through the heart.

We have not yet completely exposed, however, the wonderful character of these valvular arrangements. It would readily occur to one that the pressure of blood on the tricuspid and mitral valves, during the contraction of the ventricles, would not only be sufficient to raise the flaps to the horizontal position, but would force them beyond that, and make them open upwards into the auricles, so that the blood would still escape upwards. To prevent this there exists a remarkable arrangement. In the ventricles there are numbers of fleshy pillars projecting from the inner surface. They are called **musculi papillares** (papillary muscles). They have connected with their free points tendinous cords (**chordæ tendineæ**), whose other ends are fastened to the free edges of the valves. Now when the ventricles contract these papillary muscles contract with them and pull on the cords. The cords are of such a length that when the valve is closed they become tense, and a doubling upwards of the flap of the valve is thus prevented. In fig. 63, P points to the apex of one of the muscles, from which cords are seen passing off to a valve. As seen in that figure the inside of the heart is rough and irregular with bands of muscular fibres akin to the musculi papillares. Some of the bands, however, are connected at both ends with the muscular substance of the ventricle, others are like little cones of flesh projecting from the surface, with the apex free but with no tendinous cords. To them the term fleshy columns (**columnæ carneæ**) is applied. It is only to those from whose free extremity tendinous cords pass to the valves that the name papillary muscles is given. The semilunar valves of the pulmonary artery and aorta require no such cords, because they are not simply flaps connected by one edge only, but have a semicircular connection with the artery, just as a pocket may be sewn on to a garment. Each of the three portions of the valve forms thus a little pouch, and when the three pouches are bulged out by the recoil of the blood they meet one another. The greater the backward force of the blood the more do the pouches press back to back against one another, and any doubling back is impossible. In fig. 63, G points to the entrance to the pulmonary artery opened up, and one pouch and a half are seen, while H indicates the entrance to the aorta cut across at the level of the valve. The shape of the pouches is in both slightly indicated.

The **blood-vessels connected with the heart** are numerous. They have been partly mentioned in the preceding paragraphs. Two large veins open into the right auricle, one at the upper part—the **superior vena cava**, and the other at the lower part—the **inferior vena cava.** The superior cava brings blood from the head, neck, upper limbs, and chest, being formed by the union of two venous trunks, one from the right side of the body and the other from the left. In fig. 64, E marks the junction of the right and left trunks (K, K) from which the vena cava descends. The inferior cava is not shown in fig. 64, being behind the parts there shown. It comes from below, and brings the blood from the lower part of the body. Thus these two large veins bring the blood from all parts of the body and pour it into the right auricle; and, as we have seen, this blood all passes down into the ventricle. From the right ventricle one large vessel arises—the **pulmonary artery** (the lung artery; Latin. *pulmo*, the lung), which, at a distance of not more than 2 inches from the heart, divides into two branches of nearly equal size, one for the right lung and another for the left. Each branch, having reached the lung for which it is destined, gives off branches, and these branches again give off others, and so the branching goes on till it ends in fine hair-like vessels, capillaries, forming a rich net-work in every part of the lung. Thus the blood, driven out of the ventricle into the pulmonary artery, is by the artery distributed in fine streams throughout the two lungs. Turn now to the left auricle. Four veins open into it, two coming from each lung—**pulmonary veins,** therefore. These veins arise in the lungs from exceedingly fine vessels, which are the continuations of the capillaries of the pulmonary artery. The fine vessels unite to form larger vessels, and so on the process goes till two large veins are formed from each lung, which pass to the left auricle. The pulmonary veins, therefore, carry from the lungs to the left auricle the blood brought to the lungs from the right ventricle by the pulmonary artery, the same blood that previously entered the right auricle from the superior and inferior venæ cavæ. From the left ventricle one large arterial trunk arises—the aorta, the largest arterial trunk in the body (C, fig. 64). It passes upwards in the chest for a short distance towards the root of the neck, where it gives off branches for both right and left arms, and right and left sides of the head. (See fig. 64.) It then turns backwards and downwards and passes down along the vertebral column giving off branches on its way, and ending by dividing into branches

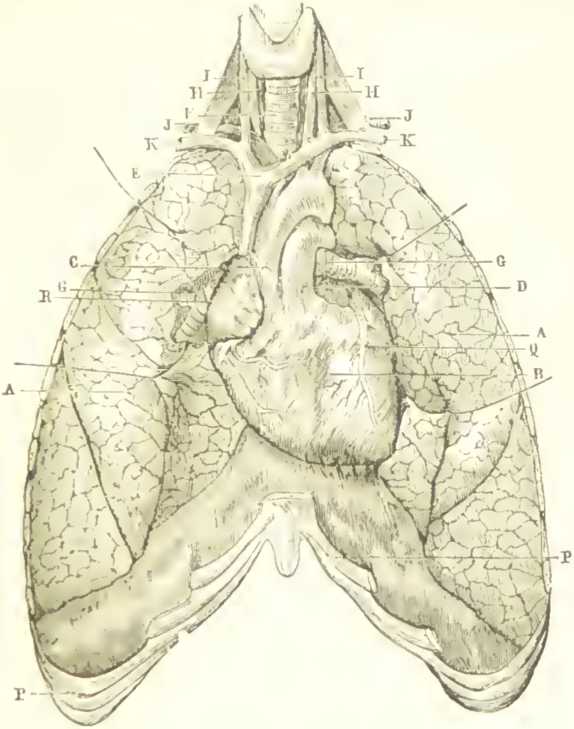

Fig. 64.—The Heart with its Blood-vessels and the Lungs.

A, the lungs pulled aside in front to show the heart, B, and the bronchial tubes, G, G. C, the aorta. D, the pulmonary artery. E, the superior vena cava, formed by the junction of the veins (subclavian) from the right and left sides, K, K. F, the windpipe. I, I, veins from the head and neck (jugular) joining K, K. H, H, arteries (carotid) to head and neck. J, J, arteries (subclavian) passing to right and left sides. P, P, ribs. Q, coronary artery. R, right auricle of heart.

for the lower limbs. It is the vessel from which branches arise which *convey* the blood to all parts of the body.

Thus we see that the blood, collected from all parts of the body, enters the right side of the heart by the right auricle, and is poured down into the right ventricle, from which it is forced along the pulmonary artery through the lungs. It is there collected by the pulmonary veins and carried to the left auricle, poured into the left ventricle, and from it forced into the aorta, by the branches of which it is conveyed to every part of the body, only to be again brought back to the right side of the heart. As we shall see in Chapter VIII., a chief object of distributing the blood through the lungs is to have it purified from certain waste substances which it has received in its course through the body, before it is again sent on its journey from the left ventricle. [The various blood-vessels that have been mentioned are shown in figs. 62 and 64.]

The means by which the muscular substance of the heart is nourished remain to be considered. Close above the semilunar valves of the aorta there arise two arteries—the **coronary arteries**, one of which passes to the right side of the heart and the other to the left. In fig. 62 C. *r.* points to the right coronary artery, and C. *l.* to the left. Between them these vessels carry sufficient pure blood to nourish the heart. After circulating through the heart substance the blood is collected by **coronary veins**, which pour it into the right auricle. Thus the heart gets its own share of the nourishment which it is its business to drive through the body.

The **Action of the Heart.**—The heart being the chief instrument in maintaining a steady flow of blood through the body, its action must be methodical and regular. It does not contract as a whole. The two auricles contract at the same instant, and the contraction of the two ventricles immediately follows. While the ventricles are contracting the auricles begin to relax, and after the ventricles have contracted they also relax. There is a period following the ventricular contraction, when the whole heart is at rest, till the auricles again contract. The order of events is thus—contraction of auricles, contraction of ventricles, pause, contraction of auricles, contraction of ventricles, pause, and so on. The contraction is called **systole**, and the relaxation **diastole**, so that the order of events might be stated as systole of the auricles, immediately followed by systole of the ventricles, and thereafter a period during which the whole heart is in diastole. The occurrences follow one another so regularly as to be called *rhythmic*, and, on that account, the **rhythm of the heart's action** is spoken of. Suppose the heart to be beating 65 to 75 times a minute, which is the average, the time occupied from the instant the auricles began to contract till, after the contraction of the ventricles and the pause, they began to contract again, would be less than a second. Of this time $\frac{1}{5}$th is occupied by the contraction of the auricles, $\frac{2}{5}$ths by the contraction of the ventricles, and the time during which the whole heart is at rest is $\frac{2}{5}$ths of the period. We know, from what has been said in previous paragraphs, that during the contraction of the auricles the blood is being poured down into the lower chambers, that immediately after they have emptied themselves they begin to relax and to be refilled from the veins, that during the ventricular contraction the blood is being forced into the arteries, the pulmonary artery on the right side, and the aorta on the left, and that during the relaxation both auricles and ventricles are refilling. We know also that during the ventricular contraction the tricuspid and mitral valves are closed, preventing the return of blood to the auricles, while the valves of the arteries are open, permitting of the blood passing into them, and that during the relaxation the tricuspid and mitral valves are open, while the valves of the arteries are closed, preventing the return of blood to the ventricles.

The **beat** of the heart. These occurrences are attended by various others worthy of note. The first of these is the beat of the heart. If the hand be laid flat on the chest over the region of the left nipple, the heart will be felt beating against the chest-wall. This is due to the fact that, by its vigorous contraction, and a slight turning movement, the apex of the heart is jerked forwards against the chest-wall. The impulse should be felt in the space between the fifth and sixth ribs, an inch below and a little to the right of the left nipple. It is important to know this position, for the heart is sometimes displaced by disease, and the beat indicates its new position.[1]

Sounds also accompany the heart's action. If the ear be applied over the heart two sounds will be heard following one another with perfect regularity. They have been imitated by uttering the syllables *lupp, dupp.* One is heard immediately after the other, then there is a pause, and then the two sounds again; and so on. They are distinguished by being called the *first sound*, and the *second sound.* The second sound is short and sharp as compared with the first. It is not certain what the first sound is due to, but while it is being produced the ventricles are contracting, the tricuspid and mitral valves are closing, the blood is rushing into the arteries, and the heart is projected against the chest. The second sound has been conclusively shown to be caused by the closing of the semilunar valves of the pulmonary artery and aorta, and while it is being produced the ventricles are relaxing, and the blood is entering both upper and lower chambers. These sounds afford indications of the greatest importance in the detection of heart disease. For, if the valves of the heart are diseased, the sounds will be either accompanied or replaced by blowing murmurs, owing to the blood rushing past roughened surfaces, and if one can detect which sound is associated with the murmur, the valve affected may be determined and the exact position of the disease fixed.

The **work** of the heart. Work done by an engine may be measured by the weight it can lift through a certain distance, or the distance through which it can lift a certain weight. Thus if one were to say a load of 100 pounds was lifted 1 foot high, a perfectly accurate idea of the work done would be gained, and it would amount to the same thing if a weight of 1 pound were lifted 100 feet high. Thus work done is measured by "foot-pounds," that is, the number of pounds weight lifted multiplied by the number of feet through which it was lifted gives the work done. The same method can be applied to measure the work done by the heart. With every contraction of the ventricle 6 ounces of blood are forced into the aorta. It has been found that if the blood were projected freely, it is sent out of the ventricle with such force that it would rise to a height of 6 feet. Thus with every stroke of the ventricle the work done is equal to raising 6 ounces 6 feet high, or, what is the same thing, 36 ounces 1 foot high. But 36 ounces are $2\frac{1}{4}$ pounds; therefore, the force exerted by the ventricle at each beat is equal to $2\frac{1}{4}$ foot-pounds. Suppose the heart beats 70 times a minute, $2\frac{1}{4}$ multiplied by 70 are equal to a force of $157\frac{1}{2}$ foot-pounds exerted by the left ventricle in one minute. Multiply $157\frac{1}{2}$ by 60, the number of minutes in an hour, and then by 24, the number of hours in a day, and the result is 226,800 foot-pounds of work performed by the left ventricle in a day. If we add to this the work done by the right ventricle, it would equal, by a rough estimate, 300,000 foot-pounds per day, that is, 300,000 pounds lifted 1 foot high; that is, a sufficient force is developed by the heart in one day to raise the body of a man weighing 150 pounds, 2000 feet in the air. That force seems enormous. It is worth noting the conditions of its development. They are *proper nourishment*, conveyed to the heart's substance by its own system of coronary vessels, and *a regular alternation of work and rest*, for we have seen that during the period of its round the heart works three-fifths of the time and rests two-fifths.

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[1] The rate of the heart's beat is affected by age, sex, posture, exercise, and various other circumstances. At birth it is about 140 per minute, in early infancy 120 or upwards, in old age it commonly falls to 60, being between 65 and 75 in the healthy adult. It is more rapid in females than in males. It is quicker when the person is standing than when lying, is quickened by exercise and excitement, is faster in the morning, and at its slowest pace at midnight.

The **nervous control** of the heart. The regular rhythmic movement of the heart is maintained by nervous influence. If a frog be suddenly killed by a blow on the head, and the chest be immediately opened, the heart will be found still beating. If a long piece of straw, fixed at one end, be laid over the heart, the free end will move up and down, showing and exaggerating the movement. More than this, the frog's heart can be entirely removed from its body, and attached to tubes, filled with nourishing fluid, from which the heart is replenished at intervals. By this means the heart can be kept beating vigorously for a whole day or more, and observations made. It has been ascertained by these and similar means that, at various places in the substance of the heart, there are nervous ganglia; that is, masses of nervous matter. It is from certain of these that there proceed, at regular intervals, discharges of nerve energy, which excite the movement. All of the ganglia, however, do not seem to excite movement; the business of one of them seems to be *to restrain.* If the exciting ganglia had it all their own way, the heart would go on contracting at a speed that would be quickly exhausting, and, if the restraining ganglion had it all its own way, the heart would stand still. The one influence, however, modifies the other, and the result is a moderate and regular activity of the heart.

Now these nervous arrangements are within the substance of the heart itself; but the organ is subject to influences from outside of itself. Two nerves are connected with the heart, the **pneumogastric** nerve (p. 279) and the **sympathetic** (p. 280). If the pneumogastric be excited by electrical shocks or in other ways, the heart slows, and, if the excitement be strong enough, stops beating, in a condition of complete relaxation and fully distended; if the sympathetic be stimulated, the heart quickens its movement, beats faster and faster, until, if the stimulus be strong enough, it stops, but this time in a condition of complete and rigid contraction. It would, therefore, appear as if the sympathetic were connected with the exciting ganglia of the heart, and as if the pneumogastric were connected with the restraining ganglion.

Now let us observe how these nervous relations act in ordinary life. A person is the subject of some emotion, and his heart is beating faster than usual; that means that the excitement is communicated from his brain by sympathetic nerves to the heart, which it stimulates to increased activity. When a person receives a blow on the stomach which causes him to faint, the explanation is that the blow has produced a profound impression on certain nerves in the belly, which have conveyed the impression to the brain, and from the brain the impression has, in turn, been carried down to the heart by the pneumogastric nerves, causing the heart to cease beating for an instant. This is of the nature of a reflex action (p. 246). If the effect on the heart be so great as to restrain its movements for any appreciable time, death is the result. It is in a similar way that sudden shocks of any kind, severe pain, &c., cause fainting, the restraining influence exerted on the heart by the stimulation of the pneumogastric momentarily suspending its movements.

The Blood-vessels.

The **Blood-vessels** form the channels along which the blood is conveyed. There are three kinds of blood-vessels, **capillaries, arteries, veins,** which differ from one another in various particulars.

The **structure of capillaries** will be first described, since they are the most delicate vessels. They are very fine tubes formed by long flattened cells (simple squamous epithelium, p. 31), united edge to edge. This is shown by staining with nitrate of silver a fine tissue, such as the inner membrane of the brain, the pia mater (p. 263), which contains capillaries in abundance. On then examining the tissue with the aid of a microscope, delicate vessels are seen traversing it in all directions.

The nitrate of silver stains darkly the cement substance between the cells, and thus the fact of the vessel being made up of cells is revealed. This is shown in fig. 65 *a*, where the clear areas, mapped out by the irregular dark lines, are the cells. A smaller vessel similarly stained is seen at *b*. At *d* in the figure there is represented a capillary unstained giving off branches so fine that the blood corpuscles would require to travel through them in single file. These are the finest branches, and have no greater diameter than the $\frac{1}{2000}$ to the $\frac{1}{3000}$ of an inch. In *b* and *d* a small body is seen in the centre of each elongated cell. It is a nucleus (p. 27). Now, in vessels larger than capillaries, outside of this layer of cells there are various coats of fibrous, elastic, or muscular tissue, according to the size of the vessel and the strength which it is necessary for it to possess.

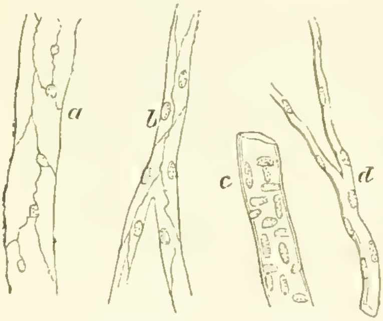

Fig. 65.—The Structure of Capillaries.

The Structure of Arteries.—Arteries have as their innermost coat—the coat next to the channel of the vessel—a delicate membrane, consisting of cells precisely similar to the wall of the capillaries. Outside of this is a coat of fibrous tissue, with an abundance of elastic fibres in it. Outside of this again is what is called the *middle coat*, consisting of elastic tissue and fibres of involuntary muscle disposed circularly round the vessel. These coats are indicated in fig. 66, which represents an artery dividing into two branches. *a a* point to the inner lining membrane of cells, *b b* to the middle muscular coat, which has been acted on by acetic acid to show the nuclei of

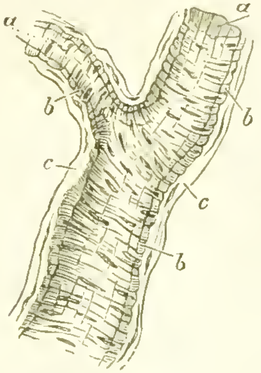

Fig. 66.—Structure of an Artery.

the transverse muscular fibres; and *c c* point to the outer coat. Fig. 65 *c* represents a small artery or vein in which the nuclei of muscular fibres running both longitudinally and transversely are shown. The outer coat of an artery consists mainly of fibrous tissue, containing also elastic fibres. In the large arteries the elastic tissue predominates, while in the small arteries the muscular coat is more pronounced. Thus the feature of the large arteries is their elasticity, while that of the small is their contractility. The importance of this is spoken of on pages 170 and 171.

The **structure of veins** is practically the same as that of arteries. They have the same coats, but they are much thinner and more flaccid. There is also this other difference, that the veins, with some exceptions, have valves, which are directed towards the heart and permit the blood to flow in that direction, while preventing its flow in the opposite direction. In a dead animal an artery may be distinguished from a vein by the stoutness and firmness of its walls, while those of the vein are soft and yielding. Also if one cuts through the artery, the tube will be seen to remain open, owing to the thickness of its walls, while the walls of the vein are collapsed and folded on one another. Arteries are, in the dead animal, generally found empty, the veins only containing blood. It was this observation that led old anatomists to give the name arteries (*arteria*, an air-vessel) to the strong open vessels, because, finding them always empty, they thought that in life they contained the animal spirits.

The **functions** of the various vessels will be noted in discussing the phenomena of the circulation.

THE CIRCULATION OF THE BLOOD.

The Systemic Circulation.—The circulation of the blood throughout the whole body is similar to the circulation through the lungs already described (p. 158). The former is called the **systemic or great circulation,** the latter the **pulmonary or lesser circulation.**

The blood which fills the left ventricle is, by its contraction, forced into the aorta, which is already filled with blood, so that, to make room for the extra quantity, it must distend, and the blood already in it must be forced onwards. As this is happening many times in a minute the blood in the aorta is continually being forced into its branches. Now as we have seen the aorta gives off branches to every part of the body, to head and neck, to the upper limbs, to the chest and the organs in it, to the organs contained within the abdominal cavity, and to the lower limbs. Thus to every region of the body from the crown of the head to the sole of the foot blood is being carried by arteries. As these arteries penetrate into the various regions and organs of the body they give off branches, which are continually becoming smaller, till they become microscopic in size and are found penetrating every part. The smallest arteries end in thin-walled capillaries, which form such a close net-work that a pin cannot be passed into a tissue without opening into some of them. The arteries, even the smallest of them, are simply tubes for conducting the blood to its destination; but the capillaries are something more, for their walls are so thin that, though continuous, they permit fluid portions of the blood to ooze through to bathe the tissues that surround them. The blood in the capillaries is, therefore, in communication with the tissues surrounding them, and exchanges material with them even as it flows through them. At length the capillaries begin to join together to form larger and larger vessels, and so, gradually, veins are formed, at first microscopic in size, but gradually the blood passes into larger veins formed by the junction of smaller ones and by the addition of other coats, till the large veins of the particular limb or organ are reached. These join the veins coming from other limbs and organs, until the two large venous trunks are formed, the superior and inferior venæ cavæ, the one coming from the upper and the other from the lower parts of the body, which carry the blood to the right auricle. From the right auricle it passes to the right ventricle then through the lungs by the pulmonary artery and its branches and back to the heart, but to the left side, by the pulmonary veins, as already described. By passing into the left ventricle the blood has completed its circuit of the body and lungs.

Thus blood which has issued from the left ventricle passes through two sets of capillaries before it returns to the left ventricle—the capillaries of the tissue which it is sent to nourish, and the capillaries of the lung. The blood which is sent to the stomach, bowels, spleen, and pancreas has, however, an unusually long circuit. After passing through the arteries of these organs, traversing their capillaries, and entering their veins, the blood reaches the **portal vein,** formed, as we have seen (p. 106), by the junction of the veins of the organs mentioned. The blood then passes through the capillaries of the portal vein in the liver and enters the hepatic vein, and so on to the inferior vena cava. Thus blood sent to the stomach and bowels, spleen and pancreas, traverses three sets of capillaries, those of the particular organ, stomach or spleen, &c., those of the portal system in the liver, and those of the lung. This is the longest route a portion of blood may take from the moment it leaves the left ventricle to the moment it returns to it. The shortest possible route is through the substance of the heart itself. A portion of blood entering the aorta, and immediately passing off by the coronary arteries (p. 160), will merely traverse the capillaries in the substance of the heart and return to the right auricle by the coronary vein, completing its circuit by passing through the lungs.

There are various things to notice connected with the flow of blood through arteries, veins, and capillaries, and associated with the differences in the structure of these vessels.

The Circulation in the Arteries.—It has been pointed out that the large arteries are specially elastic. The effect of this is not difficult to understand. Take the aorta as an example. It is filled with blood, but by the contraction of the ventricle an additional quantity is thrown into it. Sufficient room cannot at once be made by the onward flow of that which already occupies the vessel, and so part of the vessel distends sufficiently to accommodate it. As soon as the contraction of the ventricle is over the force distending the artery is diminished, and, by their own elasticity, the walls of the vessel recoil, that is, they return to their natural degree of distention. In doing this the walls press on the blood contained within them, and tend to drive the blood both backwards and forwards. The blood is prevented passing backwards by the closure of the aortic valve, and it must all pass on into the next part of the artery, which in turn distends, being already full, to receive it. The same process is here repeated; the distended wall speedily recoils and passes the blood on to a succeeding part, which, also, first dilates and then recoils on the blood within it. Thus the contraction of the heart is not the only force in driving on the blood. It is aided by the elastic recoil of the arterial walls succeeding it, and the blood is forced onwards in waves.

The **Pulse** is thus explained. If a finger be laid on a part of the body where an artery approaches the surface a throbbing movement will be felt, and the finger, if lightly applied, or better still, a piece of straw laid over the place, will rise and fall in a regular manner, and the beat, thus produced, will be perceptibly in time with the contraction of the heart. This movement is the result of the alternate distention of the vessel by the wave of blood, and the recoil of the walls by their elasticity. It does not occur at the same instant as the contraction of the ventricle, because it takes a little time for the wave to pass from the heart to the place where the pulse is felt, and it is, therefore, a little later at the ankle than at the wrist. Wherever an artery approaches the surface the pulse may be felt. The wrist is the most convenient place, but it is easily found at the temple and the inner side of the ankle. The number of pulse beats will vary with the number of heart contractions. See p. 162, and foot-note.

The **jerky movement** of the blood in an artery is seen if the vessel be cut. The blood does not issue in a regular stream, but in spurts, corresponding to beats of the heart. This enables one to ascertain readily whether a wounded blood-vessel is an artery or a vein, for the flow of blood from the latter is *continuous*. This is of importance, because if an artery be cut we know the blood is flowing *from the heart* to the distant parts of the body. If the loss of blood is to be prevented, the vessel must be closed nearer to the heart than the wound, to prevent new supplies of blood coming on to the wound. This is done by pressing with the fingers or a pad on the heart side of the wound. If, on the contrary, it is a vein that is wounded, we know the blood is flowing in it *towards the heart* from the distant part, and pressure must be exerted on the side of the wound furthest from the heart.

While elasticity is the feature of the large arteries, the **contractility of small arteries** is their characteristic. If the muscular fibres which surround a vessel contract, the channel will be narrowed and less blood will be permitted to flow through it. If the muscular fibres relax, the force of the blood within the vessel—**the blood pressure**—will cause the channel to enlarge by dilating the tube, and more blood will be permitted to flow along. Thus the diameter of the vessel may be regulated by the muscular contraction, and the quantity of blood proceeding to a tissue or organ will be thereby affected. The contraction of the muscular fibres is controlled by the nervous system, and so the nervous system regulates and controls the blood supply to the various regions of the body. How this is effected is explained on p. 174.

Bleeding from small arteries that have been wounded is arrested, to a large extent, by the contraction of the muscular coats of the vessels. Tincture of steel and such substances, when applied to bleeding surfaces, stop the flow of blood because they excite the muscular fibres to contract, and so shut the mouths of the open vessels.

The term **blood-pressure** has been used above;

what does it mean? Most people know what a burst water-pipe is, and understand that the pipe has burst because it is too weak to withstand the force of the water in it—the water-pressure. If one works an india-rubber syringe fitted with an india-rubber pipe, if a small pin-hole be in the tube, with each stroke of the syringe a jet of water will spurt from the tube, and the height of the jet will depend upon the force applied at the syringe, and will indicate by its height the pressure of the water within. Again, suppose the syringe to be steadily and uniformly worked: if a wide tube be put on, the water will flow along more easily, that is at less pressure, and if a narrow tube be put on, resistance to the flow will be offered, and the pressure will rise. If, even with a wide outflow tube, the tube at its outlet be pressed on to hinder the escape, the pressure will become excessive. Apply this to the heart and circulation. A certain pressure—the blood-pressure—is always exerted by the blood on the walls of the vessels. It could be measured by the height to which a jet of blood would rise through a hole in the vessel-wall. If the heart beats more vigorously, the pressure will rise. If, by nervous action (p. 175), the heart beating steadily, the vessels be dilated, the pressure will fall, because the vessels are wider, and it will rise if they become contracted. If some resistance be offered to the flow through the capillaries, the blood-pressure will increase on the side of the arteries and fall on the side of the veins. It should also be plain that the blood-pressure will be greatest where the arteries open out of the heart, and will diminish towards the capillaries, and be least where the veins open into the heart.

The **Circulation in the Capillaries** must be considered next, since the blood flows from arteries into capillaries. The best way to observe the circulation in the capillaries is to fix up a living frog in such a way that the web of its foot is stretched so as to be viewed through a microscope. A fine transparent tissue is seen with clumps of black colouring matter here and there. The tissue is cut up by channels pervading it in all directions, some wide, some extremely narrow. Along these channels blood is streaming. In the wide vessels it is dashing along with apparently great speed, the red corpuscles streaming in crowds down the centre, while the white corpuscles are seen rolling along nearer to the walls of the vessel; in the narrowest vessels there is evidently room for only one corpuscle at a time, and the corpuscles range themselves along, accommodating their shape to the turns and corners so as not to stick in the channel. The noticeable feature is that the current is continuous. When it is remembered that the flow in the arteries is jerky, and that the capillaries are continuous with the arteries, this seems strange. Why is it that the intermittent movement of the blood in the arteries is not continued into the capillaries? The explanation is found in the elasticity of the arteries. Were the blood-vessels rigid tubes, then there would be ejected from one end just the quantity of fluid forced in at the other, and in the same intermittent way. The blood encounters resistance in the capillaries, it cannot get along so quickly as in the arteries, the arteries are, therefore, kept constantly distended, and their elastic force is brought into full play. During the pause after each contraction of the heart the elastic walls of the arteries are pressing on the blood they contain, and are following up the force of the heart. It is as if there were two propelling forces, the one following the other so smoothly and regularly that there is no stoppage in the onward movement. If the elastic tube is long enough the result is that, by and by, the wave-like movement of the fluid in it becomes less and less perceptible, till it finally disappears, and the intermittent movement is converted into a continuous flow. It must be observed, however, that it is only where there is sufficient resistance to the progress of the fluid that this can happen, for if there is little resistance the elastic reaction is not brought into play, and the jerky movement persists. The next thing noticeable, connected with the capillaries, is the thin walls of the vessels, so that the oozing of fluid, already referred to, for purposes of nourishing the tissues, is easily understood. Another feature that one remarks is that every minute part of tissue is so surrounded with capillaries that it cannot fail to receive nourishment from all sides.

Generally speaking, every organ and tissue of the body is permeated by capillary blood-vessels, even bone being interpenetrated by them. Tissues so traversed by vessels are said to be **vascular**. There are, however, a few tissues which are **non-vascular**, that is, they have no such system of vessels within them. These are epidermis and epithelium, in other words, the surface layer of the skin and mucous membrane, and nail, hair, the substance of the teeth, and cartilage or gristle. Such tissues, however, are closely related to moist vascular tissues, from which they are able to suck up nourishment.

The **Circulation in the Veins** is characterized by a continuous flow, the wave-like movement having been completely lost in the capillaries. Besides the force from behind—the force that is transmitted through the capillaries from the arteries—other agents enter to impel the blood in its progress through veins. Chief of these are the valves which are present, with exceptions, in veins, and permit the flow of blood towards the heart, but close if there is any attempt at a backward flow. Contracting muscles, by pressing on veins, and, consequently, on the blood they contain, aid in the venous part of the circulation.

Besides the forces indicated in preceding paragraphs, the action of the heart, the elasticity of the arteries, the action of valves in the veins, and the effect of muscular contraction, there are others which aid in the circulation of the blood. The most notable are the suction action produced by the relaxation of the heart after each contraction and the movements of breathing. Inspiration (p. 178) tends to lower the pressure exerted on the walls of the vessels in the chest, and this acting most markedly on the thin-walled veins, assists the flow of blood towards the heart, expiration tending to help the discharge of blood from the heart.

The **Rapidity of the Circulation** varies. It is quickest in the arteries and slowest in the capillaries. In the capillaries there is a much greater channel space, and since the quantity of blood entering the heart is always the same as that leaving it, the blood must flow more slowly in the capillaries if the balance is to be maintained. Thus from the aorta onwards to the capillaries the speed diminishes, and from the capillaries through the veins it increases to the heart. In the capillaries the rate is estimated as 1 to 1½ inches *in a minute*, and in one of the larger arteries 10 to 15 inches *in a second*. The length of time taken for a portion of blood to travel the whole round of the circulation is, in the horse, about half a minute. It has been estimated by injecting into one of the veins of the neck a substance—ferrocyanide of potassium—easily detected by chemical tests, and noting what length of time elapsed before it was found in the blood of the same vein of the opposite side of the neck.

Nervous Control of the Circulation.—The walls of the blood-vessels are largely muscular. The muscular fibres are beyond the control of the will. Nevertheless they are controlled by the nervous system, by the agency of nerves distributed among the muscular fibres. The nerves are called **vasomotor** (*vasa*, vessels), and they are governed from a centre—the **vasomotor centre**—situated in the medulla oblongata (p. 270). The influence on the vessels may be briefly stated thus: By the nervous energy continually reaching the muscular walls they are kept in a moderate state of contraction or tone, so that the channels are maintained at an average size. If the vasomotor nerves are stimulated more than usual, the muscular walls contract more, the size of the channel is diminished, the quantity of blood flowing through it is correspondingly diminished, and the supply to the part lessened. If the stimulus is less than usual, the amount of contraction is lessened, the vessels dilate by the force of blood within them, the channel becomes widened, and the supply to the part is increased. Now various influences from various parts of the body, or from the brain itself, may reach the vasomotor centre and exite it to increased activity; the nerves are thereby stimulated and the vessels contract. But there is another curious effect that may be produced on the centre, what is called an *inhibitory* or restraining effect, whereby the normal influence of the centre is, for a time, suspended, the tone of the vessels becomes diminished, and their channels immediately widen. The production of blushing and pallor are thereby explained.

Blushing is caused by some emotion which acts on the vasomotor centre and diminishes its activity. The tone of the vessels being lessened they dilate, more blood rushes along their channels, and the skin becomes redder and hotter by the increased quantity of blood. It is usually in the face that this is manifested.

Pallor is just the reverse condition. Some emotion so acts on the vasomotor centre as to increase its activity. The blood-vessels contract, less blood flows through them, and the part becomes pale. Thus the same emotion that causes redness of one person's face may produce paleness of another's.

More than this, the heart and the blood-vessels are related by nervous communication in a curious way. Connected with the heart there is a nerve called the **depressor** nerve. Suppose the blood-vessels in a considerable part of the body to be unduly contracted. Blood flows through them less easily, and the heart has more work in forcing it along. This may occur to such a degree that the heart is unnecessarily burdened. Its labour may become so heavy as to threaten fatigue, and danger of exhaustion may arise. At this period an influence passes from the heart by the depressor nerve to the vasomotor centre. The action of the centre is restrained, the tone of the vessels is diminished, by the pressure of blood within them they dilate, the blood flows along easily, and the heart is relieved. This is just an instance of how all the bodily functions are regulated and controlled by the nervous system, and made to serve the good of the whole organism.

Chapter VIII.—RESPIRATION.

The lungs are the organs of respiration, that is, of breathing. Everyone knows that the continuance of the acts of breathing is necessary to life, and that if respiration be suspended, as it is in choking, strangling, drowning, &c., for even a few minutes, death results. The vast importance of this bodily function, and the great and constant danger of any disease that seriously interferes with its due performance, will be fully appreciated if a general statement of the position it holds in the processes of life be here given by way of introduction to this chapter.

It is (at p. 69) pointed out in Chapter V. how food is prepared to form part of a nourishing fluid—the blood, and Chapter VI. describes other sources of blood-forming material. Chapter VII. describes the nature of the blood and the means by which it is distributed throughout the body. It points out also (p. 145) that the purpose of the blood is to nourish each minutest element of the body, to give to it raw material for its use in growth and activity, and that it not only gives up to tissues something to maintain them, but acts as a means of carrying away from them the products of their activity, waste substances which, if allowed to remain, would impair their health and vigour, and that thus the blood becomes impoverished as much by poisonous materials added to it as by nourishing materials taken from it. Now, as already said, between Chapter V. and Chapter VI., the sources of new nourishment to the blood have all been exhausted, with one exception, that of oxygen gas; but none of the means, by which poisonous waste matters cast into the blood are removed, has yet been considered. The lungs supply the oxygen, and on this ground must be considered as organs of blood formation. But at the same time that they supply oxygen, and by the same method, they remove from the blood carbonic acid gas, and that gas is one of the principal waste substances. On this ground, therefore, they rank as blood purifiers. If, then, the lungs are seriously interfered with, a twofold blow is dealt at the blood—the very stream of life—for the risk at once arises of its supply of oxygen being diminished, without which it is unable to nourish the tissues; and the risk also arises of the carbonic acid being allowed to remain, whose presence renders it poisonous to the tissues. With the consideration of the lungs, then, we complete our view of the sources of supply to the blood, and begin our view of the means of its purification.

THE APPARATUS OF BREATHING.

The Windpipe or Trachea.—The lungs may for the moment be regarded as sacs situated in the chest, which communicate with the outside by means of a series of tubes. The chief of these is the trachea or windpipe, which passes down the front of the neck into the chest. It is about 4½ inches long. It is surmounted by the **larynx** (*the box of the windpipe*), a box-like structure made of cartilage (gristle), which contains the organ of voice, to be described later in this chapter. The larynx may be felt projecting at the upper part of the neck, and in some people it visibly projects. The projection is called the **pomum Adami**, Adam's apple. The upper end of the larynx opens into the pharynx or throat, and is provided with a lid—the **epiglottis**—which closes the opening under certain circumstances. The parts will be understood by referring to the accompanying figure, which represents the larynx and the windpipe. L is the larynx, formed mainly of two pieces of cartilage, called the **thyroid** (*Th.*) and the **cricoid** (*Cr.*). A little below *Cr.* the larynx passes into the windpipe. *e* of the figure points to the tongue-shaped epiglottis, shown raised, but when lowered capable of covering over the upper opening of the windpipe. Now let the reader refer to fig. 43, p. 95, and the relation of these to surrounding parts will be understood. On that figure *ep* points to the epiglottis; the line pointing to *g* is a little below the level where the larynx passes into the windpipe (*w*). It will be seen also that the larynx opens into the back of the throat, the opening being guarded by the epiglottis, and that the gullet (*g*) is just behind the windpipe. Further, it will be seen that the finger, placed on the skin where the turn is made from under the chin on to the front of the neck, will touch the upper edge of the larynx, and that this is below the root of the tongue. Before air can enter the trachea, then, it must pass through the mouth or nostrils (still refer to fig. 43) into the pharynx (*ph*), past the raised epiglottis, through the larynx, and so into the trachea. Now it will at once occur to any one that if air can enter into the larynx or windpipe, so can water, or anything one may be drinking, or for that matter anything one may be eating. This accounts for food or drink, or things being held in the mouth, a coin, &c., slipping accidentally into the windpipe. But why does this happen only accidentally? Why is it not a constant occurrence? Let any one put his finger on the front of the neck, on the notch at the top of the larynx, and then let him swallow. He will feel the larynx suddenly lifted

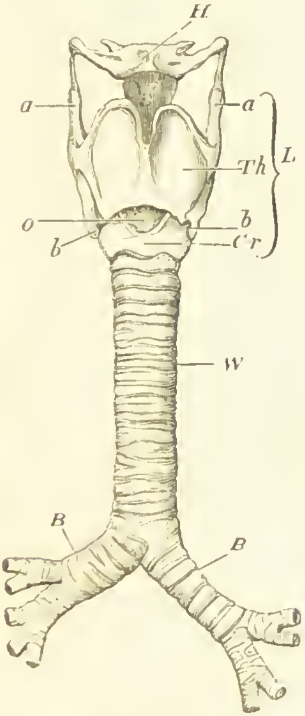

Fig. 67 —The Larynx and Windpipe.

L, larynx, formed of *Th.* and *Cr.*, thyroid and cricoid cartilages. *a*, *a*, *b*, *b*, processes of thyroid (see p. 197). H, hyoid bone. *e*, epiglottis. W, windpipe. B, B, bronchial tubes.

up, and when the swallowing is over drop down again. By this action the larynx is raised up to be under cover of the root of the tongue, and at the same time the epiglottis folds down. These movements are effected by nervous action, and it is only accidentally, when the parts are taken unawares, as it were, that anything can drop into the larynx or windpipe.

The Bronchial Tubes.—The lower end of the windpipe is situated in the chest, and there it divides into two branches (fig. 67), one of which passes to each lung. Each branch is called a **bronchus** (Latin *bronchus*, a windpipe), and is called right or left as it passes to the right or left lung. The place where the tube enters the lung is called the root of the lung. Each bronchus after passing into the lung divides into smaller tubes, and these again into still smaller, and so the division and subdivision go on till the whole lung is penetrated by branches, the final subdivisions of which are of extreme fineness. To all these divisions and subdivisions the general term **bronchial tubes** is applied. The smallest of them are only about the $\frac{1}{50}$th of an inch in diameter. Fig. 68 represents A, the windpipe, branching into B, the left, and C, the right bronchus, and these into smaller bronchial tubes, such as D. This figure is, however, only a representation, for the multitude of tubes of extreme fineness into which the larger tubes ultimately break up cannot, of course, be shown, though some attempt is made to represent them on the side on which B is placed.

Now there are some remarkable features worth pointing out in the structure of the trachea and bronchial tubes. Unless some provision was made to the contrary the tubes, even the largest of them, would readily collapse, their walls would fall together with the slightest pressure, and the fair-way for the passage of air would be closed. The walls are, however, stiffened by pieces of cartilage (gristle). In the windpipe the pieces of cartilage are C-shaped, the deficient part being behind resting on the gullet. In fig. 67, W points to one of the cartilaginous rings, and in fig. 73 is seen how they terminate behind. In the bronchial tubes plates of cartilage are disposed in the circumference of the walls, and act like the rings of the windpipe, keeping the tubes open. In the smallest tubes, however, the cartilage is absent, and the tubes become liable to spasmodic closure. In the windpipe the defective portion of the rings behind is closed by a band of muscular fibres of the involuntary

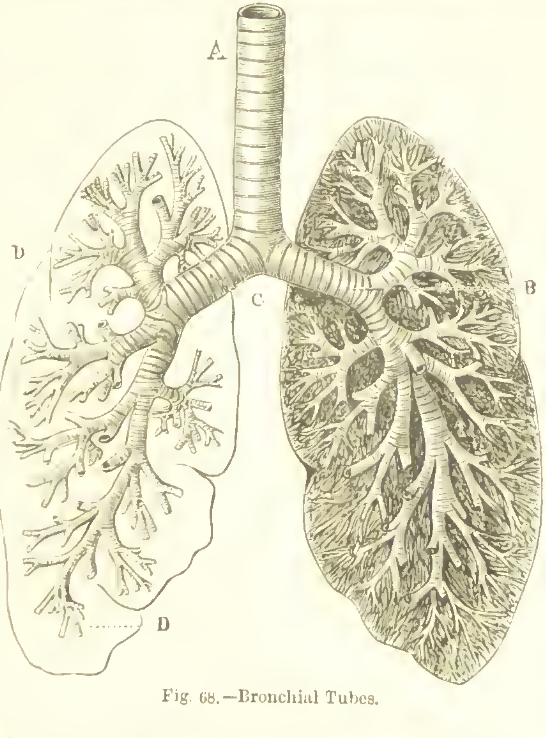

Fig. 68.—Bronchial Tubes.

kind (p. 64), while in the bronchial tubes there is a middle coat formed of a continuous layer of involuntary muscular fibres disposed round the walls. Both windpipe and bronchial tubes have elastic fibres running the length of the tubes. The inner surface of the tubes is lined by mucous membrane continuous through the larynx with that of the throat, mouth, and nostrils. This mucous membrane is covered by a layer of stratified columnar epithelium, the topmost layer having cilia such as has been described on p. 29, and in fig. 5. The mucous membrane is provided with glands, which, by their secretion, keep the membrane moist. These anatomical details are interesting because of the purposes which the structures are fitted to serve. As already pointed out, the cartilage keeps the tubes open. The elastic tissue confers elasticity on the tubes, permits them to stretch readily with the movements of the neck, &c., and to return to their normal condition when the stretching is over. The cilia of the epithelium keep up a constant waving movement, all in the same direction, namely, upwards, and thus any excessive secretion or defluxion is gently urged upwards to the top of the windpipe, from which it is expelled by a cough. Material is thus prevented from passing downwards and accumulating in the small tubes, so that they are in ordinary circumstances kept clear. It is believed that the muscular layer, specially of the smaller tubes, acts in a similar way, sweeping upwards by its contractions matter to be expelled. An eminent physician has, on this account, called them "scavenger muscles." It may be mentioned here that this muscular coat, in unhealthy conditions, may by its excessive contraction produce a serious difficulty in breathing. If muscular spasm occurs in the smallest tubes, unprovided with cartilage, it may close the tubes, prevent the passage of air, and so occasion severe difficulty of breathing. This spasm would be produced among other things by excessive nervous action, and is believed to be the cause of the difficulty of breathing in nervous asthma. But, again, it should be noticed that if one attempted to breathe an irritating gas the muscular coat would be stimulated to contract, would bar the way to the entrance of the hurtful gas, and so be of great benefit.

It has been noted that the smallest bronchial tubes have no plates of gristle in their walls. They lose also the hair-like processes of the epithelial cells, which are reduced to one fine layer.

The Lungs.—In an earlier paragraph of this chapter the lungs were, for the moment, represented by two bags or sacs communicating by means of tubes with the external air. This would almost be a proper description of the lungs of some of the lower animals, if we add to it that the sacs have depressions in the inner surface of their walls resembling the cells of a honey-comb. In the lungs of the higher animals and of man the structure is much more complicated, although built up, so to speak, on the type of the elementary structure just noticed. If one of the smallest bronchial tubes be traced to its extremity it is found that it leads into a passage wider than itself, and that from that passage there open out on all sides honeycomb-like cells. This is represented diagrammatically in I of fig. 69, where *b* indicates the termination of the bronchial tube, *h h h* the passage into which it leads, and *c* the cells opening off the passage. The cells are called **air-cells or alveoli** (Latin *alveolus*, a small cavity), and the passage is the **alveolar passage** or **infundibulum**, because of its widening out from the place where it arises from the bronchial tube. The whole arrangement of passage and air-cells springing from the termination of a bronchial tube is called an ultimate lobule. II of fig. 69 shows two such lobules from the lungs of a newly-born child (magnified twenty times) as they appear when not opened up, as they are in I. Now, each such ultimate lobule of a human lung is a very small miniature of the whole lung of some of the lower animals. So that a whole human lung is a kind of assemblage of miniature lungs of the type of the lower forms. For several infundibula are grouped or packed together, and thus form a lobule, larger than the ultimate lobule, from a quarter to half an inch in diameter, and bound by connective tissue. Several lobules are bound together in a similar way to form a lobe of the lung. The right lung has three such lobes, and the left two.

The walls of the air-cells are very thin, consisting of delicate elastic and connective tissue, and lined inside by flat transparent cells. In the connective tissue run capillary vessels belonging to the pulmonary artery and veins (p. 158). Now, if fig. 69, I, is attentively considered it will be seen that these delicate vessels running in the connective tissue are surrounded on all sides by air-cells, so that the blood flowing through them is only separated by the thin walls of the vessels, and by the delicate tissue of the air-cells from the air which these cells contain. The deep significance of this will be apparent immediately. It need only be noted now that such an arrangement is perfectly adapted for exchanges taking place between the blood in the capillaries and the air in the air-cells.

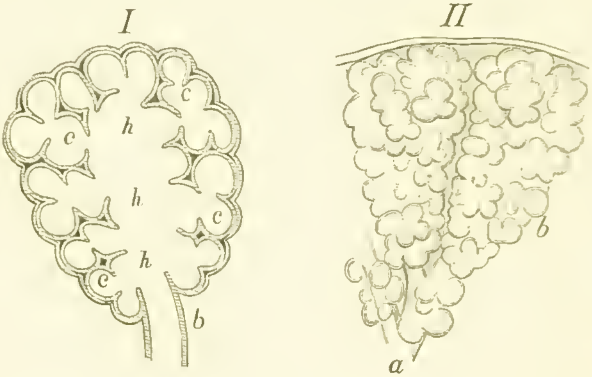

Fig. 69.—Air-cells of the Lung.

Each lung is surrounded by an investing membrane—the pleura. Like the investing membrane of the heart (p. 150) the pleura of each lung is in a double layer. One layer closely envelops the lung and at the root of the lung is reflected on to the wall of the chest cavity of its own side, which it lines. The two layers thus form between them a shut sac, a serous cavity. No cavity exists, however, in health, but the two layers glide on one another, and the inner surface secretes a slight amount of serous fluid to prevent friction. It is inflammation of this membrane that is called *pleurisy*.

Through the root of the lung vessels pass to and from the lung. The pulmonary artery enters carrying blood from the right side of the heart to the capillaries of the air-cells, to be purified by contact with the air the cells contain. The pulmonary veins leave the lung by the root to pass to the left side of the heart, carrying the purified blood. Branches from the great artery—the aorta—called **bronchial arteries**, enter the lungs at the root carrying pure blood to be distributed over the bronchial tubes and among the connective tissue of the lungs, to maintain their nourishment. Lymphatic vessels also pass out by the root to join the thoracic duct (p. 126). For lymphatic channels are distributed through the lungs over the bronchial tubes, and are in direct communication with the air-cells. It is by means of the lymphatic vessels that matters are absorbed from the lungs, and afterwards may be poured into the current of the circulation, after passing through glands.

The lungs are also supplied with nerves.

The position of the lungs is shown in fig. 61 (p. 149). One lung occupies the right side, the other the left. They meet in the middle line, but the lung of the right side reaches farther down in the middle line than that of the left, because a deep notch exists in the front border of the left into which the heart projects. When both lungs are well filled with air the heart is covered except the portion in the position of this notch. As seen in the figure (61) a line drawn downwards and to the side to the level of the tenth rib, from about the position where the sixth rib joins the breast-bone, will indicate the extent to which the lungs reach downwards. On the left side, however, the lung extends downwards farther than on the right side by the breadth of a rib. On each side the lungs reach upwards higher than the first rib, the apex of each lung passing up into the neck on each side for an inch and a half above the level of the first rib.

The Diaphragm.—The base of the lungs rests on the partly muscular partly tendinous partition—the diaphragm—which separates the cavity of the chest from that of the belly. This partition is one of the main agents in the act of breathing, and its position must be understood. It forms the floor of the chest cavity and the roof of the abdominal cavity, just as the roof of one room is the floor of the room above it, and separates the two from one another. It is not flat, however, but arched, the arch being directed upwards. This will be understood by a reference to fig. 70, which is a section of the body carried from back to front, and shows the cavities of chest and abdomen, with their contents removed. The diaphragm is also shown in section, arching from B in front. It is seen that it is convex towards the chest and concave towards the belly. It is attached all round, to the breast-bone and ribs in front, to the ribs at the side, and to the ribs and spinal column behind, being attached lower down at the sides and back than in front. On its upper surface the bases of the lungs rest, the pleuræ being connected with it and the investing membrane of the heart also. This is well shown in fig. 46 (p. 101), where C points to the diaphragm. It also shows that immediately below the diaphragm and mainly on the right side the liver is situated, while mainly to the left side is the stomach. Now the diaphragm, being partly composed of muscle, is capable of contraction. When it contracts, the sides being fixed by their attachments to the ribs, &c., its centre will be pulled on and, therefore, lowered. That is to say, the floor of the chest will be lowered, the cavity of the chest will there-

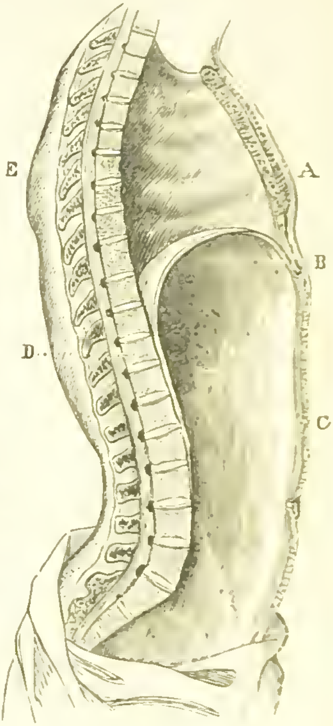

Fig. 70.—The Diaphragm.

by be enlarged, and room will be afforded for the expansion of the lungs. On the other hand, when the diaphragm becomes relaxed, its contraction being over, it will rise by its own elasticity, the cavity of the chest will be diminished, and air will be forced out of the lungs to afford room for the rise. As we shall see, it is chiefly by the regular alternation of contraction and relaxation of the muscular portion of the partition that the movements of breathing are carried on.

THE MOVEMENTS OF BREATHING.

If a healthy person be observed it will be noticed that the act of respiration or breathing consists of a regular series of movements. With the taking in of breath the chest rises and the belly is slightly pushed outwards. That is immediately followed by the falling of the chest, the return of the belly to its former size, and the output of air. Succeeding this is a pause, and the same set of movements is thereafter repeated. The first act is called **inspiration** (Latin *in*, in, and *spiro*, I breathe), and the second is **expiration** (Latin *ex*, out, and *spiro*, I breathe). What is, therefore, called the **rhythm of respiration** consists of three parts, inspiration, expiration, pause, one after the other in regular order, the three parts forming one respiration. In an adult healthy man the number of respirations should be about 16 per minute, but the number varies with age, that of a newly-born child being 44.[1] During the time of one respiration there should be about 4 beats of the heart. Besides age other things affect the number of respirations per minute. Exercise

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[1] The following table gives the average number of respirations per minute at different ages:—

Age.	Number of Respirations per minute.
Newly-born child,	44
1–5 years,	26
15–20 ,,	20
20–25 ,,	18
25–30 ,,	16
30–50 ,,	18

In very old people the number may fall to 12 per minute.

increases the number, while rest diminishes it. The number is smallest during sleep. Mental emotion and excitement quicken the rate; the mere paying attention to one's own breathing affects the rate. Of greatest consequence is the effect of disease. In fevers the rate is increased and the rapidity of the pulse is increased in proportion. In diseases specially affecting the lungs, such as bronchitis, pleurisy, consumption, &c., the rate of breathing is very marked, and usually where the lungs specially are involved, the increased rate of the breathing is out of all proportion to the increased rapidity of the heart. In such diseases there may be as many as 60 or 70 respirations per minute.

The Cause of the Respiratory Movement may be made plain by a simple experiment. Let a glass bell-jar with a neck and open mouth be taken (fig. 71). Let two small india-rubber bags (*b b*) be connected to the end of a glass tube (*c c*), and let them be introduced into the jar, the glass tube passing through a tightly-fitting india-rubber cork. Then let a leather floor (*e*) be fixed to the jar, shaped as shown in fig. 71, so that it may be pushed up into the jar into the position marked *e*, or pulled down into the position marked *d*. The floor must also be air-tight. Now here we have a chamber (*ch*) entirely shut off from the outside air, and hanging in it are two bags whose cavities have no connection with that of *ch*, but communicate with the outside air by the tube *c c*. The air in the chamber and the air in the bags are both under the same pressure, that of the atmosphere, a little more than 14 lbs. to the square inch. Now suppose the leather floor to be in the position of *e*, let it be caught by the hand and pulled down to the position of *d*. By this movement the cavity of the chamber is increased in size, and, as it has no

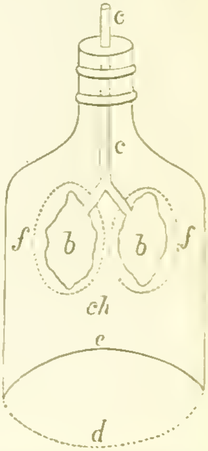

Fig. 71.—The Mechanism of Respiration.

communication with the outside, no air can enter to occupy the increased space, and consequently the air already present expands to fill the large cavity, that is, it becomes rarefied. The result is that the pressure of air in the interior of the chamber is less than it was before. But the pressure of air in the inside of the elastic bags (*b b*) is undiminished, so that the pressure within them is greater than the pressure outside of them, that is, in *ch*. In consequence the bags yield to the pressure of air within them, they expand, air entering by the tube *c c*, and they continue to expand until their increased size makes up for the addition to the size of *ch*, until they occupy the increased space. Next let the leather floor be pushed up, the size of *ch* is diminished, the bags are pressed on from within, air is expelled from them, so that they become smaller, and the original state of affairs is restored. Now this is precisely what takes place in the chest and lungs. Let us compare the two things step by step. The chest is a chamber, formed of bony walls, the ribs, connected in front with the breast-bone and behind with the spinal column (see fig. 23, p. 48). The spaces between the ribs are occupied by muscles—the **intercostal muscles** (Latin *inter*, between, and *costa*, a rib), while large masses of muscle clothe the chest in front and behind, layers of fat and connective tissue covering them, and the skin being outside of all. The chest has for its movable floor the diaphragm already described. It is an air-tight chamber comparable in every respect to *ch* of fig. 71, with this additional advantage, that its walls are movable as well as its floor. It has suspended in it the lungs, whose air-cells communicate with the outside by means of the bronchial tubes and windpipe, but have no connection with the general chest cavity, and which are represented by the elastic bags (*bb*). This much, however, must be noticed, that the lungs and other contents of the chest completely fill its cavity, and do not simply occupy a small space in it. The contraction of the muscular fibres of the diaphragm causes it to descend, and thus increases the size of the chest cavity. The pressure of air in the lungs would thus come to exceed that in the chest, but that a quantity of air, entering the lungs, causes them to expand sufficiently to fill up the increased space (just as pulling down the leather bottom of *ch* causes the elastic bags to distend), and thus the equality of pressures is maintained. As soon as the contraction of the diaphragm is over, it relaxes, returns to its original position, reduces the size of the chest cavity, and air is expelled from the lungs to permit them to diminish in size. After a short pause the diaphragm again descends by contraction of its muscular fibres, and the round of operations is repeated.

The cavity of the chest is enlarged from above downwards by the descent of the diaphragm, but this is not all. Its walls are also movable. The ribs may be raised by the contraction of the intercostal and other muscles, and by their rising they push forward the breast-bone. The chest cavity is by this means enlarged from side to side and from before backwards. Thus the cavity of the chest is increased in three directions, from above downwards, from side to side, and from before backwards, by the descent of the diaphragm and by the elevation of the ribs. As a result the expansion of the lungs is made more vigorous. This is the cause of the breathing in of air, of *inspiration*, which is seen to be essentially *a muscular act*—the result, that is to say, of a series of muscular contractions. But as soon as the contraction is over, the ribs tend, by their weight, to fall down into their position of rest, the muscles tend to relax, and the lung tissue, which is elastic and has been stretched by the expansion, tends to return to its original less stretched condition, as an elastic band which has been stretched recovers itself as soon as the stretching force is removed. The result is, the original size of the chest cavity is restored, and a quantity of air is expelled from the lungs. So *expiration* is seen to be essentially the result of an *elastic recoil*, and not of active muscular contraction. While this is the mechanism of *ordinary quiet breathing*, other forces are brought into play when breathing is difficult, as when the windpipe or bronchial tubes are obstructed, notably as in asthma, where there is spasmodic closure of the smaller bronchial tubes, and in diseased conditions of the lungs, which create an obstacle to their expansion. In such cases many additional muscles are called into play, which contract vigorously for the purpose of pulling up the ribs more completely and compelling the lungs to expand, producing what is called **forced inspiration.** Thus asthmatic people, who are awakened out of sleep by a spasm, instinctively raise their arms to grasp something above the level of the head. This is for the purpose of obtaining a fixed point of support from which muscles, passing from the arms and shoulders to the chest, may act in forcibly raising the ribs. Again, when the output of air is hindered, **forced expiration** results. Breathing-out ceases to be the result of a mere elastic recoil, and muscles are called into play, such as those passing up from behind to the lower ribs, whose contraction pulls down the ribs, and those of the abdominal walls, whose contraction presses on the contents of the belly and forces them up against the lower surface of the diaphragm, causing it to ascend.

Varieties of Breathing.—The two main agents in the production of breathing being the descent of the diaphragm and the elevation of the ribs, the movements visible from the outside vary according to the predominance of one or the other.

In men and in children the action of the diaphragm is marked. Its descent diminishes the space in the cavity of the belly, presses on the organs therein contained, and causes an outward movement of the abdominal walls, so that the movements of the walls of the belly are specially noticeable. This is called **abdominal** or **diaphragmatic** breathing.

In women the action of the ribs is more pronounced, and the chest rises and falls more than in men. This is **costal** (*costa*, a rib) breathing.

Abdominal breathing is well seen in infants. It ought, therefore, to be plain how the common practice of binding children tightly round the belly is extremely injurious, since it interferes with the natural performance of the respiratory act.

These natural varieties of breathing are altered in various ways by disease. A painful disease of the belly will compel a man to prevent movement of the abdominal walls as much as possible, and then the costal variety will take its place, while some disease of the chest will often cause a woman to suspend her natural method of breathing, and to adopt the abdominal form. In this way one is sometimes able to form an idea of the seat of a disease simply by watching the movements of respiration, and observing whether they are of the kind that would be expected in ordinary states of health.

Facial breathing is the term applied to the movements of the nostrils, seen particularly well when breathing is laboured. It consists in an expansion of the nostrils with each inspiration, and a return to their previous condition in expiration. In children with bronchitis, or inflammation of the lungs, it is marked. Indeed whenever it is specially noticeable, unless after considerable exertion, it should call attention to the condition of the lungs.

The **Result of the Movements of Respiration** is alternately to introduce and to expel from the lungs a certain quantity of air. When a man breathes quietly, 30 cubic inches of air enter the lungs with each inspiration, and 30 cubic inches pass out with each expiration. After taking an ordinary breath a man may, by forced inspiration, by taking the deepest possible breath, introduce into his lungs an additional 100 cubic inches. Again, after breathing out an ordinary breath (30 cubic inches) one may by an effort expel 100 cubic inches more. But even after the utmost expulsive effort 100 cubic inches remain in the lungs which cannot be expelled. The 30 cubic inches that pass in and out in quiet breathing form what is called the **tidal air.** The 100 extra cubic inches one may draw in with effort are the **complemental air,** and the 100 extra cubic inches one may expel with effort, after breathing out the ordinary amount, form the **supple-**

mental air. The 100 cubic inches which remain and ~~cannot be~~ expelled form the **residual air.** Thus the lungs of an adult man are capable of containing altogether 330 cubic inches of air, thus composed:—

Complemental air	100	cubic	inches.
Tidal ,,	30	,,	,,
Supplemental ,,	100	,,	,,
Residual ,,	100	,,	,,
	330		

If, then, a person, after taking the deepest possible breath, proceeds to breathe out as much as he can, he expels—

Of complemental air	100	cubic	inches,
,, tidal ,,	30	,,	,,
,, supplemental ,,	100	,,	,,

making a total of 230 cubic inches, forming what is termed the **vital capacity** of the chest, after which there remain in the lungs the 100 cubic inches of residual air. The vital capacity is then determined by the amount of air a person can expel with the utmost effort after taking the deepest possible breath, and ought in a healthy adult man of average height and weight to equal 230 cubic inches. In women it is less than in men. There are various forms of instruments for measuring the amount. They are called **spirometers,** or measurers of breathing, and are some form of what is familiar to every one under the name *gasometer*. The vital capacity varies with height and weight, increasing with increasing height above the average, and slightly decreasing with increased weight above the average.

The Nervous Control of Breathing.—The movements of breathing go on without the necessity of any interference on our part, without our consciousness of them being necessary. During sleep their regularity is even greater than when we are awake, and when awake we may alter the movements to some extent, but cannot altogether arrest them. The breath may be held for a time, but speedily the need for breath gets the mastery, and a long deep breath is drawn. Now it has been shown that there is a particular part of the nervous system that presides over the respiratory function. It is situated in the medulla oblongata (p. 270). Destruction of this part is followed by immediate stoppage of breathing and death. On this account this region of the medulla has been called the *vital knot* (*nœud vital*). Here there is, that is to say, a nervous centre for breathing. It is injury to this centre that proves fatal in cases of broken neck. From it regular discharges of nervous activity pass outwards to the nerves that supply the diaphragm and other muscles of respiration, and stimulate them to the regular rhythmic contraction which, as we have seen, is the cause of the movements of the chest, the expansion of the lungs, and the entrance of the air. But the centre is capable of being influenced in various ways. Chiefly it is affected by the condition of the blood. When the blood becomes more venous the action of the centre is excited, and more vigorous respiratory movements occur. On the other hand, if a series of very deep breaths be taken, so that the blood becomes more richly supplied with oxygen than usual, a considerable time will elapse before the need of another breath is felt, and after the interval the breathing will be resumed, the first inspiration being feeble, and those succeeding gradually increasing up to the normal. The meaning of this is that the presence of the unusual quantity of oxygen in the blood has calmed the respiratory centre, so that for a time it has ceased its regular rhythmic discharge, till, as the blood begins to become venous, the normal stimulus is restored. This explains how persons may train themselves to remain under water for some time with no arrangements for permitting breathing to go on. They take a series of deep inspirations, take into the blood, as it were, a stock of oxygen sufficient to last for a little time, and before they dive under the surface. The respiratory centre is stimulated by the presence of excess of carbonic acid in the blood, and soothed by the presence of excess of oxygen.

It is the great excess of carbonic acid present in the blood, in cases of persistent obstruction to the breathing, that produces the excessive stimulation of the centre, indicated by laboured breathing and the convulsions of suffocation. The centre may, however, be stimulated in other ways. Nerves of sensation supplying the general surface of the body are capable of conveying influences to it leading to its excitement, and ending in vigorous respiratory movements. Thus cold water dashed on the face or chest, a sudden draught of cold air on an exposed part of the body, &c., are speedily followed by a deep, long-drawn breath. The cold water or air has irritated sensory nerves, and the stimulus has been conveyed to the centre, producing a discharge of nerve force to the muscles of inspiration. The action of the respiratory centre may also be modified by influences from above—from the brain—by mental emotions, for example. One nerve in particular conveys impressions to the centre for respiration, affecting through it the movements of breathing. It is the **pneumogastric** or **vagus** nerve (p. 279). Some fibres of that nerve end in the lungs, and thus from the lungs themselves, in some way not yet understood, influences pass upwards to the centre in the medulla oblongata which affect the respirations. By means of that nerve the centre is kept informed, as it were, of the conditions of the lungs themselves.

Even as the oxygen and carbonic acid gas in the blood act directly on the centre, so drugs that have been taken and have passed into the circulation may act on it. Notably does morphia influence it, markedly reducing its activity. In morphia poisoning it is maintenance of breathing that must chiefly be attended to.

THE PURPOSE OF BREATHING.

We must now try to understand what is the object of the remarkable and complicated structure of the lungs and of the movements which have been described.

The Gases of the Blood.—On p. 145 it has been shown that the blood contains three gases, oxygen, carbonic acid gas, and nitrogen, partly dissolved in it, partly in chemical union with certain of its constituents. The nitrogen need not be taken into account. The oxygen is to be considered as part of its nourishing material which the tissues, to which the blood is distributed, require to carry on their processes. The carbonic acid gas is a waste substance which the tissues produce by their activity, and which the blood carries away from them. As the blood flows through the body much oxygen is removed from it, carbonic acid gas being substituted; and if the efficiency of the blood to nourish the tissues, in this respect, is to be maintained, it must always be receiving new supplies of oxygen, and a means must be at hand of ridding it of its excess of carbonic acid gas. This double function it is the business of the respiratory process to perform. The blood that is sent out from the left side of the heart on its mission to supply the body is of a bright scarlet hue (the colour of arterial blood), while the blood that returns to the right side of the heart, after its mission is accomplished, is of a dark purple colour (the colour of venous blood). This change in colour takes place in the capillaries, the vessels whose walls are so delicate as to permit of free interchange between the blood in the vessels and the tissues outside of them. In short, it is due to the fact that, in the capillaries, the blood gives up oxygen to the tissues, and receives from them carbonic acid gas. This is corroborated by chemical analysis, which shows that arterial blood contains more oxygen and less carbonic acid than venous blood,[1] and by the experimental fact that if the dark-coloured venous blood be shaken up with oxygen it becomes of a scarlet colour, while arterial blood shaken up with carbonic acid gas becomes purple. Now, as mentioned on p. 158, the ven-

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[1] This is shown in the following table, in which is stated the quantity of oxygen and of carbonic acid in 100 volumes of arterial blood, and 100 volumes of venous blood:—

	Oxygen.	Carbonic Acid.
Arterial blood	20 volumes.	39 volumes.
Venous ,,	8 to 12 ,,	46 ,,

The quantity of nitrogen is the same in each, viz. 1 to 2 volumes.

ous blood, returned from the body, is conveyed to the right side of the heart, and thence by the pulmonary artery to the lungs, through which it is distributed in capillary blood-vessels to be gathered up into the pulmonary veins and carried to the left side of the heart. But when it leaves the right side of the heart the blood is purple-coloured, and when it enters the left side it is scarlet. That is to say, while passing through the capillaries of the lungs it has been converted from venous into arterial blood. In other words, in its progress through the lungs it has given off its excess of carbonic acid gas and obtained a new supply of oxygen. So that while in the general capillaries of the body the blood is rendered impure by being deprived of much of its oxygen and being laden with carbonic acid, in the capillaries of the lungs the process is reversed, and the blood is purified by being rid of its excess of carbonic acid and by having its proper quantity of oxygen restored. Now it has been already stated (p. 184) that the capillaries of the pulmonary artery, through which the blood flows on its way from the right to the left side of the heart, are distributed over the walls of the air-cells of the lung, and that the air-cells are so numerous and closely packed, and their walls, as well as those of the capillaries, so thin that there is no obstacle to an interchange taking place between the blood in the vessels and the air in the air-cells. It is manifestly here, then, that the change occurs which transforms the dark-coloured, carbonic-acid-laden venous blood into the bright-hued blood refreshed with oxygen. How does that conversion occur is the next question.

Exchanges between the Blood and the Air in the lungs. It is a well-known physical law that if two different liquids be placed in a vessel in contact with one another and be left alone, without any disturbance whatever, they do not remain separate, but proceed straightway to mix, and in time there will be a perfect mingling of the two liquids. Suppose, for example, that water and spirit are taken, and, for the sake of seeing the experiment going forward, that the spirit is coloured

red, that the water is placed in a glass jar, and when it is perfectly still that the spirit is carefully poured on the top of it, so carefully that the two layers, one below of colourless water and the other above of coloured spirit, are quite distinct from one another. If the jar be set aside, it will be observed that the coloured spirit does not long remain all on the top, though it is lighter than water, but that the colour gradually passes downwards into the water, until in time the whole is coloured—an equal mixture of water and spirit is found in the jar. This is called **diffusion of liquids.** Now the same thing occurs with gases, though the process is not visible. If one glass jar be filled with carbonic acid gas and a second with oxygen gas, and if the jar containing the oxygen be placed upside down on the top of the jar containing the carbonic acid, the jars being fitted mouth to mouth, then we have practically one glass vessel, composed of two jars united at their mouths, the lower part containing carbonic acid gas and the upper oxygen, the two being in contact with one another. In spite of the fact that the lower gas is much heavier than the upper one, the two proceed to diffuse, the heavy one passing up into the light, and the light one passing down into the heavy. In course of time, the time is not long, the vessel contains a perfect mixture of carbonic acid gas and oxygen. This is **diffusion of gases.** On pp. 89 and 90 it is stated that two liquids will mingle even when separated from one another by a membrane, and similarly two gases will mingle even when separated from one another by a membrane. Thus if a bladder be filled with oxygen, and if, after being firmly closed, it be placed in a jar containing carbonic acid gas, the oxygen will pass through the walls of the membrane to mingle with the carbonic acid, and the carbonic acid gas will pass inwards to mix with oxygen, until the bladder and the jar contain equal mixtures of the two gases. Moreover the process will be aided by the walls of the bladder being moistened with water. This is owing to the fact that liquids dissolve gases. Water exposed to an atmosphere of oxygen will lick up or, to speak more correctly, will absorb some of the oxygen. It will do the same with other gases; and other liquids also absorb gases, though one liquid will absorb more of one gas than of another. Nay, one liquid, already containing a gas dissolved in it in quantity, is not thereby prevented from absorbing a quantity of another gas. So that, if the walls of the bladder be wet, one side is moistened with water containing oxygen in solution, and the other side is moistened with water containing carbonic acid gas in solution, and an interchange takes place between the two solutions, as described on pp. 89 and 90, so that oxygen passes outwards and carbonic acid gas passes inwards. Not only do liquids dissolve gases naturally, but they may be made by pressure to lick up much more than the usual quantity. As every one knows, a bottle of aerated water contains water charged with carbonic acid gas. The gas is forced into the bottle by great pressure and the water compelled to dissolve it. The pressure is so great that, in order to compel the water to retain the gas, the bottle must be tightly corked and the cork bound down by wire. As soon as the cork is removed, the gas comes off with great force and produces the sparkling or effervescence of the water, while sometimes the pressure of gas in the water is so great as to blow out the cork or burst the bottle. Gas dissolved in a liquid exerts pressure on that liquid in its efforts to escape. If the pressure outside the liquid be less than that of the gas in the liquid, the gas will escape and come off; if the outside pressure be equal to that of the gas in the liquid, or greater, it will remain dissolved. Suppose, then, water containing oxygen in solution be placed in a jar filled with oxygen. If the pressure of gas in the jar be greater than that in the liquid, the water will take up more oxygen, but if it be less it will give off some oxygen, the result being that, in the end, the pressure of gas in the liquid and that outside of it become the same. In the same way if a liquid containing both oxygen and carbonic acid gas be exposed to an atmosphere of mixed oxygen and carbonic acid gas, unless the pressure of the two gases are the same in the liquid and in the atmosphere an exchange will take place. If the pressure of oxygen in the liquid be less than the pressure of that gas in the atmosphere, oxygen will pass into the liquid until both are equal; and if the pressure of carbonic acid gas in the liquid be greater than that outside, carbonic acid gas will pass off from the liquid till both are equal, so that the liquid will gain oxygen and lose carbonic acid gas, while the atmosphere will lose oxygen and gain carbonic acid. The same process will take place even though the liquid be separated from the atmosphere by a membrane, and will occur more readily, as we have seen, if the membrane be moistened on both sides.

Now these facts explain to some extent the changes that occur in the blood in the lungs, for the conditions we have been speaking of are exactly fulfilled. Blood containing oxygen and carbonic acid gas is flowing in a multitude of tiny streams through the walls of the air-cells of the lungs. The air-cells contain a mixture of the same two gases. The blood is separated from the air in the air-cells by a thin membrane, namely, the delicate walls of the capillaries and of the air-cells, and the membrane is kept moist by the blood on the one side and by secretion from glands on the other. It has been found that the pressure of oxygen in the blood is less than that in the air-cells, and that the pressure of carbonic acid gas in the blood is greater than the pressure of the same gas in the air-cells. Consequently oxygen passes through the membrane from the air-cells into the blood, and carbonic acid gas passes through the membrane from the blood into the air-cells. The blood thus gains oxygen and loses carbonic acid, while the air-cells lose oxygen and gain the latter gas. At the same time the blood, by having its proper quantity of oxygen restored to it, and its excess of carbonic acid gas removed, changes in colour from purple to scarlet, from venous to arterial blood. It is re-invigorated and purified.

This much must further be noted, that the gases are not simply dissolved in the blood, but partly in chemical union with it, and this modifies to some extent, probably aids, the process.

It will readily occur to any one that the result of this process will speedily be that the air-cells will be largely deprived of their oxygen and will contain chiefly carbonic acid gas. The pressure of oxygen will soon be even less in the air-cells than it is in the blood, and that of carbonic acid gas greater, so that the process would be reversed, oxygen taken from instead of added to the blood, and carbonic acid gas added to it instead of taken from it. This would make the blood more unfit than ever to nourish the body and more poisonous to it than before. It is evident that if the exchange is to continue of the proper character the air in the air-cells must be constantly renewed, its oxygen restored and its carbonic acid gas removed. How this is accomplished is the next question to consider.

Exchanges between the Outside Air and that of the Air-cells.—The air which we exhale during the act of expiration is very different in character from the external air which we inhale. Both contain principally the same three gases, though in different quantities, as the following table shows:—

	In 100 parts of	
	Air inspired.	Air expired.
Oxygen	20·8	15·4
Nitrogen	79·2	79·3
Carbonic Acid	·04	4·3

In other words expired air contains roughly 5 per cent less oxygen and 5 per cent more carbonic acid than inspired air; the air taken into the lungs loses oxygen and gains carbonic acid. There are also other differences. Expired air is hotter because it has been in contact with the warm air-passages, and it contains more moisture than the external air also from contact with the moist lining membrane of the passages. This is readily observed by breathing on a cold surface, on which the moisture condenses. In expired air there is also a small quantity of animal matters, which give to the air its stuffy smell.

The quantity of oxygen thus removed from the external air in 24 hours by the breathing of an adult person, as well as the quantities of carbonic acid gas and water given out in the same time, have been carefully estimated. About 18 cubic feet of oxygen are consumed daily by an adult man at rest. The same amount of carbonic acid gas is given out, and would be represented by a piece of ± 1/2 pure charcoal weighing 9 ounces avoirdupois. The quantity of carbonic acid, however, varies according to circumstances, increasing up to the age of thirty and then diminishing, being increased also by external cold and by exercise, and being affected by the kind of food taken. The amount of water, exhaled as vapour, varies from 6 to 20 ounces daily; on an average it is about half a pint.

The explanation of the difference in the composition of the air inhaled and the air exhaled is simple. During the pause that follows an act of expiration the lungs, that is the bronchial tubes and air-cells of the lungs, are still filled with air. That air, particularly in the air-cells, must be different from fresh air, because the blood is continually drawing oxygen from it and adding carbonic acid to it. When an inspiration occurs the lungs distend, and 30 cubic inches of fresh air enter to fill up the increased space. The new supply occupies only the upper air-passages. An expiration immediately follows the inspiration, but the 30 cubic inches that have previously entered are not expelled. A like quantity is exhaled, but it contains only about one-third of the 30 cubic inches just inhaled. For the supply of fresh air has no sooner entered the lungs than it proceeds to mingle with the air already there, to diffuse into it, and two-thirds of it have already passed down a considerable way towards the air-cells before the expiration, which follows its entrance, occurs. By the process of diffusion the fresh supply passes downwards towards the air-cells, increasing the quantity of oxygen already in the air in the lungs and diluting the carbonic acid. Of the air given out of the lungs in a breath, while one-third is formed of air that has entered just previously to the expiration, the remainder is air from the lungs charged with carbonic acid and deficient in oxygen, which has been displaced by the fresh air. The purpose of breathing is thus apparent: it is to restore to the air in the air-cells of the lungs the quantity of oxygen of which it is being regularly deprived by the blood, and to rid it of the excess of carbonic acid imparted to it by the blood. The two processes that have been now described must keep pace with one another: the process, by which the blood takes oxygen from the air in the air-cells and gives to it carbonic acid, must be counterbalanced by the process by which a certain quantity of fresh air is drawn into the lungs to restore the lost oxygen, and a certain quantity of air is expelled from the lungs to remove the excess of the hurtful gas.

A survey of the ground that has been gone over reveals how the structure of the lungs, the arrangement of the blood-vessels in the walls of the air-cells, and the mechanism of the distention and recoil of the chest and lungs, are all adapted to work together for this one end, namely, to facilitate exchanges of gases between the blood and the air.

VENTILATION.

It has been said that if no provision existed for regularly renewing the air in the air-cells, it would become so deficient in oxygen and so charged with carbonic acid gas that the proper exchanges could not take place between it and the blood, which instead of being purified would become more impure. That remark has a wider application. By the process of breathing we remove oxygen from the atmosphere and add to it carbonic acid, so that if the external air is to remain fit for respiratory purposes it must, like the air in the air-cells, be continually renewed. Ventilation is the term applied to the means by which the due renewal of the external air is accomplished in inclosed spaces. Suppose a man were to be shut up for a long time in a confined space into which no fresh air could enter, by and by the external air would approach more and more to the character of the air in his lungs, the purification of the blood would cease, and continued life would be impossible. Long before this, however, the impurity of the atmosphere would be revealed, by headache, languor, and oppression. The presence of from $1\frac{1}{2}$ to 3 parts of carbonic acid in every 1000 of our atmosphere is liable to produce headache and giddiness in those breathing it. The problem of ventilation is to remove bad air and supply fresh without causing draughts. In order that sufficient pure air may be present in rooms, &c., in which persons are living, it has been estimated that for each individual there should be a space of, on an average, 1000 cubic feet, and that 2000 cubic feet of pure air per head per hour should be supplied to maintain a proper standard of purity of air in the apartment. It is the excess of carbonic acid whose effects have been chiefly noted. Deficiency of oxygen also causes marked effects, producing difficulty of breathing (dyspnœa) and suffocation (asphyxia), the prominent feature of which is convulsions. It is curious that a tolerance for vitiated air can be established within limits. That is to say, a person may become accustomed to breathe, without any signs of inconvenience, a very impure air which another, coming directly from the fresh air, could not tolerate for a moment.

MODIFIED RESPIRATORY MOVEMENTS.

Coughing is produced by some irritation specially in the upper part of the windpipe and the larynx. As a result a deep breath is drawn, the opening of the windpipe is closed, and then suddenly burst open by one or several rushes of air, which pass out by the mouth. The object of this is to dislodge and carry away in the rush the material that is the cause of the irritation.

Sneezing is caused by an irritation of the nostrils or eyes, producing results similar to those in coughing, the air, however, escaping by the nostrils. In the beginning of a cold in the head it is the cold air irritating the inflamed lining membrane of the nose that causes the repeated attacks of sneezing. In some forms of inflammation of the eyes the stimulus of light produces sneezing. The eyes are usually kept shut by the sufferer, and the attempt to open them ends frequently in a sneeze.

Sighing consists of a prolonged and slow inspiration, followed by a similar expiration.

Yawning is a very deep inspiration, and is accompanied by movements of the lower jaw, so that the mouth is widely open.

In **Hiccough** there is a sudden inspiration, abruptly checked by the closing of the opening of the windpipe (the *glottis*). The sound that it produces is due to the entering air striking against the closed glottis. It is occasioned by irritation of branches of the pneumo-gastric nerve ending in the stomach.

Laughing consists of a series of short spasmodic expirations, succeeding a long breath, the vocal cords, whose movements produce voice, being thrown into activity. It is accompanied by characteristic movements of the face.

Crying is similar, and is associated with different facial movements.

In **Sobbing** there is a series of short convulsive inspirations.

VOICE.

The **Organ of Voice** or **Larynx** forms the upper part of the windpipe. It is constructed of various curiously shaped pieces of cartilage (gristle), connected together by bands of ligament, and is clothed outside by muscles, and inside by a mucous membrane continuous with that of the rest of the air-passages. Fig. 72 shows the larynx and windpipe stripped of muscles. The larynx (L) is seen to be formed of two pieces of cartilage (Th and Cr), one placed above the other. The upper of the two is the **thyroid** cartilage, and the lower the **cricoid** cartilage.

The thyroid (Greek *thyreos*, a shield) is formed of two extended wings meeting at the middle line in front in a ridge; above and from the sides two horns project upwards (*a*, *a*), which are connected by bands to the hyoid bone (H) from which the larynx is suspended. The hyoid bone itself is attached by muscle and ligament to the skull. It lies at the root of the tongue, and the finger can feel it at the angle of junction of the chin and neck. From the under surface of the thyroid two horns (*b*, *b*) project downwards to become jointed to the cricoid. The thyroid cartilage thus rests and is movable on the cricoid, movable forwards or backwards, but not from side to side. The cricoid cartilage is shaped like a signet-ring (Greek *krikos*, a ring), the narrow part of the ring being in front. Owing to this narrowness a small space (*o*) is left in front between the two cartilages. The space is closed by membrane. It is through this space that an opening is often made in cases of threatened suffocation owing to some obstruction higher up. The operation is known as **laryngotomy** (cutting the larynx), and is to be distinguished from **tracheotomy**, in which the windpipe is opened. The appearance of the larynx is very different when viewed from behind as in fig. 73. The thyroid cartilage is not complete behind, while the cricoid is broader than in front. The cricoid carries, perched on its upper edge behind, two other cartilages, of great importance in the production of the voice.

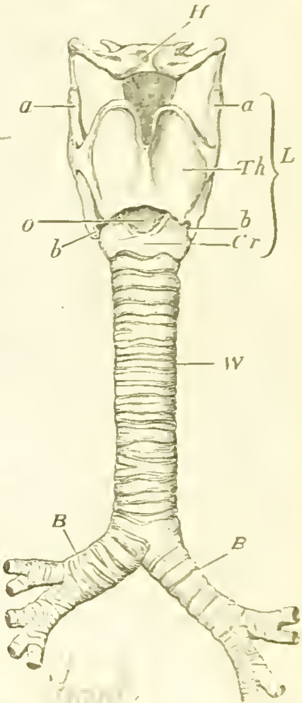


Fig. 72.—The larynx (L): windpipe (W); and bronchial tubes (B B): e, epiglottis: *Th.*, thyroid cartilage: *Cr.*, cricoid cartilage, forming L the larynx. For other references see text.

the **arytenoid** cartilages (Ar fig. 73). They are pyramidal in form as shown in the figure. On their summits are perched small pieces of cartilage, and, when in their natural position, the two form a shape resembling the lip of a ewer, hence their name (Greek *arutaina*, a pitcher).

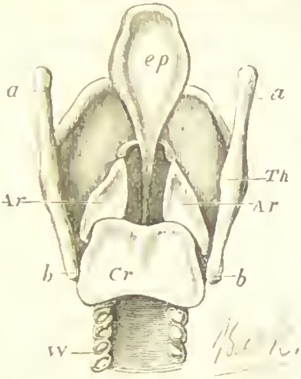


Fig. 73.—The Larynx (from behind), the soft parts being removed.

ep. epiglottis, capable of folding down on the entrance to the larynx like a lid and so closing it. See p. 178. The letters not mentioned in the text apply to the same parts as those of Fig. 72.

Now these various cartilages form a framework on which muscles and mucous membrane are disposed. Thus towards the front, one muscle passes from the cricoid up to the thyroid on each side, and when the muscle on each side contracts, the thyroid cartilage is pulled downwards and forwards on the pivot its lower horns form with the cricoid. Another muscle passes from each arytenoid cartilage behind to the thyroid cartilage, and when it contracts it pulls up the thyroid to its original position. Other muscles will be noted immediately.

The mucous membrane, which lines the inside of the box formed of the cartilages described, is thrown into various folds. In particular, one fold passes horizontally outwards from each side towards the middle line at the level of the base of the arytenoid cartilages. The free edge of each fold is formed by a band of elastic fibres that passes from each arytenoid cartilage straight forwards to become attached to the thyroid cartilage. These folds are called the **true vocal cords,** by whose movements voice is produced. They are called *true* vocal cords because above them are folds of mucous membrane called the *false* vocal cords, which take no part in the production of voice. The true vocal cords, projecting towards the middle line, encroach upon the space, and reduce the communication between the part of the larynx above them and the part below to a mere chink. This chink is called the **glottis** (from Greek *glotta*, the tongue) or the **chink of the glottis**. Fig. 74 will perhaps render this more easily understood. It represents the larynx, &c., viewed from behind, with all the soft parts in connection with it. On looking down, the folds forming the true cords (*c*) are seen, inclosing a V-shaped aperture, the glottis, the narrow part of the space being towards the front. Now by the contraction of various muscles the form of the aperture may be changed. The vocal cords may be brought so closely together that the space becomes a mere slit. Air forced through the slit will throw the edges of the folds into vibration and a sound will be produced. Variations in the form of the opening will determine variations in the sound. This, briefly, is the mechanism of the production of voice. If all the muscles of the larynx be relaxed the folds do not project nearly so far towards the middle line, the aperture of the glottis is wide, and air may enter and leave the windpipe during the acts of breathing without throwing the cords into vibration so as to produce any sound.

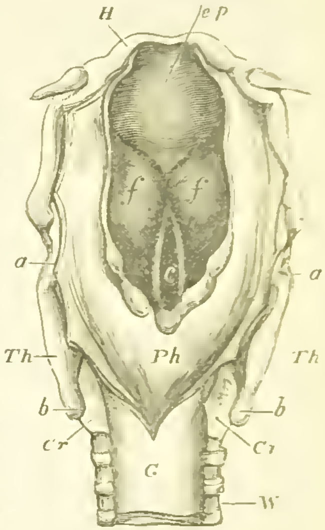


Fig. 74.—View of Larynx from behind with all the soft parts.

f, false cords; *c*. placed in chink of the glottis is between the true vocal cords; Ph. pharynx; G. gullet. The other letters are the same as in Figs. 72 and 73.

The **Production of Voice** is thus due to arrangements precisely similar to those of some musical instruments. The organ of voice is, indeed, a reed-instrument, the sound produced by the vibrations of the reed or vocal cords being modified by the tubes above and below. All musical sounds are due to movements or vibrations occurring with a certain regularity, and they differ in loudness, in pitch, and in quality. Loudness of the sound depends on the extent of the vibrations, pitch on the rapidity of the vibrations, and quality on the admixture of tones produced by vibrations of varying rates of rapidity related to one another. A tuning-fork vibrating 100 times per second gives out what is called a pure tone. If several other tuning-forks, vibrating at rates which are multiples of 100, say 200, 300, 400, &c., be thrown into vibration, the sounds emitted by them will blend with the sound of the first or **fundamental** tone, and the quality of the sound will be changed though its pitch remains the same. The tones that have been added are called **overtones.** The quality of a musical sound, therefore, depends on the overtones in it. Thus if the same note be produced on a piano, a violin, and a trumpet, the quality of the note of each will be markedly different, though the three notes are of the same pitch, the difference being due to the different overtones present in each. Human voices uttering the same note differ in quality, because the construction of the vocal apparatus of one individual favours the production of a different set of overtones from those of another.

In the production of the voice, then, there are to be noted the arrangements for (1) the vibration of the cords to produce sound, (2) the regulation of the loudness of the sound, (3) the variation of the pitch of the sound, and (4) the determination of the quality of the sound.

(1) In order that the cords may be thrown into proper vibration they must be brought close together and parallel to one another, so that only a narrow slit intervenes between them, through which air is driven with some degree of force. The vocal cords are brought together, so that the space between them is narrowed to a slit, by the action of a muscle which passes from the cricoid cartilage to the outer angle of the arytenoid cartilages. When the muscle of each side contracts the arytenoid cartilages are caused to turn on their bases, so that the vocal cords attached to them are brought close up to one another. Other muscles assist in the manœuvre. This

having been accomplished a strong expiration drives the air from the lungs through the slit between the cords, and throws them into movement. The vibration is little in amount, but very rapid. Other muscles are connected with the arytenoid cartilages which cause them to rotate in an opposite direction, so separating the vocal cords and widely opening the glottis. By means of an arrangement of mirrors, called the **laryngoscope**, devised in modern times, this operation can be easily seen. A person is seated upright in a chair, a lamp, throwing a strong light, being placed on a table at his side and slightly behind him. In front of him an observer sits, who has a slightly concave mirror fixed on his forehead. The person opens his mouth, and the observer arranges the mirror so as to catch the light from the lamp and reflect it in a bright beam into the person's throat. The observer then takes a small plane mirror, not so large as a shilling, set at an angle on a long stem, and having slightly warmed it, passes it to the back of the person's throat, the person's tongue being pulled gently forwards meanwhile. The observer so places the plane mirror that the light from the mirror on his forehead is thrown on to it, and is then reflected downwards to illuminate the larynx. When it is skilfully done, the observer is able to see in the plane mirror a view of the illuminated larynx, with its lining membrane and vocal cords. When the person is breathing quietly, the chink of the glottis is seen widely open, but as soon as he utters a sound, as that of *a* in *far*, the cords are seen to advance quickly towards the middle line, so that the passage is completely closed but for the narrow slit between them.

(2) The extent of movement of the cords will vary with the force of the outgoing current of air, and thus the loudness of the sound will increase with greater force of expiration.

(3) The pitch of sound depends, as we have seen, on the rapidity of the vibrations, and that is determined by two circumstances—the length of the cords and their tightness, for the shorter and tighter a string is the

higher the note which its vibration produces. The vocal cords of women are about one-third shorter than those of men, hence the higher pitch of the notes they produce. The cords of tenor singers are also shorter than those of basses and baritones. In children the vocal cords are shorter than in adults. In boys, at the period of puberty, the larynx enlarges. This is accompanied by an elongation of the cords, and a consequent change in the pitch of the voice, which becomes lowered. In popular language the voice is said to *crack*. Thus age and physical development determine the pitch of the voice. Voluntary variations in pitch are due to the fact that the tension or tightness of the cords can be varied at will by muscular movements. It has been pointed out (p. 207) that the thyroid cartilage can be pulled downwards and forwards over the cricoid by the action of the crico-thyroid muscle. Now the front ends of the vocal cords are attached to the inner surface of the thyroid, and when it is pulled forwards they are stretched, provided the arytenoid cartilages to which their other ends are connected are fixed. The more strongly the thyroid cartilage is pulled on, the higher will be the pitch of the note produced by the vibration of the cords, because the greater will be their degree of tightness. It is believed by some, also, that the vocal cords may be shortened by muscular action causing the cords to overlap one another, so that part of their length is "stopped," and so prevented vibrating. This would also increase pitch, just as a violinist varies the pitch of a note produced by his violin string by "stopping" it at varying distances. It has been suggested that it is such a "stopping" action that determines the production of the falsetto voice.

In opposition to muscles, whose contraction tightens the cords, are others which pull up the thyroid cartilage, and otherwise produce relaxation.

(4) The quality of the voice depends on physical conditions of the cords, their degree of smoothness, elasticity, thickness, &c. Moreover, the form of the windpipe, larynx, throat, mouth, &c., takes part in determining

quality. In fact, the air-passages both below and above the vibrating cords act as resonators, or resounding chambers, and intensify and modify the sounds produced by the cords. Indeed, the sounds emitted by the cords would be feeble but for the intensifying action of the air-passages. By their form, however, they are fitted to intensify some notes more than others. The quality of an individual's voice is as much determined, therefore, by the shape and general structure of his throat, mouth, &c., as by his vocal cords. It may be remarked that a knowledge of this fact shows the necessity of the mouth being properly opened during speech, and especially during singing. Each person has the power to alter the shape of his mouth, and so is able to adapt it to a great extent to intensify any particular sound he wishes to utter.

In the ordinary production of voice, therefore, there is a great variety of muscular movement of a very delicate character; how complicated and rapid must be the movements executed by a singer! It is impossible to conceive the delicacy and complexity of the movements voluntarily executed by the well-trained and skilful singer, who adapts vocal cords, larynx, throat, mouth, &c., with speed and precision, so as to produce accurately the desired sounds. The muscular movements involved are all produced in response to nervous stimuli reaching the muscles from the brain.

Voice is, then, produced in the larynx, and is modified by the rest of the respiratory passages.

Speech is to be distinguished from voice. It may exist without voice. A whisper is speech without voice. Speech is due to sounds produced by the action of the throat, mouth, and nose. In ordinary talking it is accompanied by vocal sounds. In speech, then, are vowel and consonantal sounds.

Vowel sounds are sounds produced in the larynx, whose quality is markedly altered by the shape of the resounding chambers above, especially the mouth. Thus, let a person sound a particular note, and utter the vowel sound, *a* (as in *father*), *e* (as *a* in *fate*), *i* (as *ee* in *feet*), *o* (as in *cold*), and *u* (as *oo* in *foot*), and he will find that continuing to sound a note of the same pitch he can produce all the vowel sounds, by alterations in the shape of the mouth principally.

Consonants are sounds produced by interruptions of the outgoing current of air, but in some cases are preceded or followed by vocal sounds. The interruption to the outgoing current may take place by movements of the lips, as in pronouncing *p, b, f, v.* These are **labial** consonants (Latin *labium*, a lip). *M* is also a labial consonant, in which there is a vocal sound suddenly interrupted by a lip movement.

When the tongue, in relation with the teeth or hard palate, obstructs the air, **dental** consonants are produced, *d, t, l, s.* *N* is a dental consonant, a vocal sound being suddenly checked by the tongue and teeth. *S* is also a dental sound, caused by the teeth offering an obstruction to a continuous rush of air past them.

Gutturals are due to the movements of the root of the tongue in connection with the soft palate or pharynx, such as *k, g, ch, gh, r.*

In the production of *ng*, a vowel sound is interrupted by the approximation of the root of the tongue to the soft palate. It is thus a guttural sound.

CHAPTER IX.—EXCRETION: THE KIDNEYS AND BLADDER.

In the previous chapter the method by which the blood is purified to the extent of being deprived of its excess of carbonic acid gas, through the agency of the lungs, is described. But carbonic acid gas is not the only waste substance derived by the blood from the tissues. There are others, as important, specially such as are the result of the decomposition in the body of nitrogenous (p. 23) substances. If they are allowed to remain in the body death is the result. To separate these waste substances there must be some special apparatus provided. That special apparatus will be found to exhibit a structure ultimately exactly resembling that which has already been described as the structure of a secreting gland (p. 92), that is a basement membrane on one side of which are active cells, and on the other side a copious blood supply, from which the cells may derive raw material. In the case of organs for the separation of waste, the material produced by the cells is meant to be expelled; it is therefore called an **excretion**, as opposed to a secretion which is elaborated for further use in the body, and the organ is called an excretory organ.

Such excretory organs are the **kidneys and skin**. The liver is both a secretory and excretory organ, since it produces material alike for further use and for expulsion. The kidneys and bladder are designed for the expulsion specially of the waste products of nitrogenous material. The substances are separated in a liquid form, the urine; and as the urine is formed slowly, after passing from the kidney it is collected in a reservoir—the bladder—until some quantity has accumulated, when it is discharged by a voluntary effort.

THE KIDNEYS.

Their Structure.—The kidneys are two in number, and are situated in the cavity of the abdomen, one on each side of the spinal column, between the eleventh rib and the crest of the haunch-bone. The liver is above the right kidney, the spleen (p. 132) above the left; while both lie close against the back wall of the abdomen, so that the intestinal canal is in front of them. The human kidney is about 4 inches long, 2 inches broad, and 1 inch thick, and weighs usually about 5½ ounces. The shape of the human kidney is the same as that of a sheep, or rabbit, and is well known. The connections of the kidney are shown in fig. 75, which represents the outline of the abdomen, opened, the intestinal canal being removed. A kidney appears on each side of the spinal column, blood-vessels being connected with each, and from each a tube—the **ureter**—passes downwards to the bladder, situated in the cavity of the pelvis.

If a kidney be cut open in the direction of its length an appearance exhibited in fig. 76 is seen. The ureter (U), where it joins the kidney expands into a wide cavity (P), the **pelvis** (*pelvis*, a basin) of the kidney. Into the pelvis conical processes of the fleshy substance of the kidney project. The processes are called pyramids, or the **pyramids of Malpighi,** after the anatomist who described them, and in the human kidney there are about twelve of them. The apex of each pyramid is invested by a part in continuation of the pelvis, which surrounds it like a cup or calyx. Now the fleshy-looking substance of the kidney consists of very fine tubes, the **tubuli uriniferi** (or urine-carrying tubules). In the circumference of the kidney the tubules run a very irregular course, but towards the centre they run a straight course. The distinction

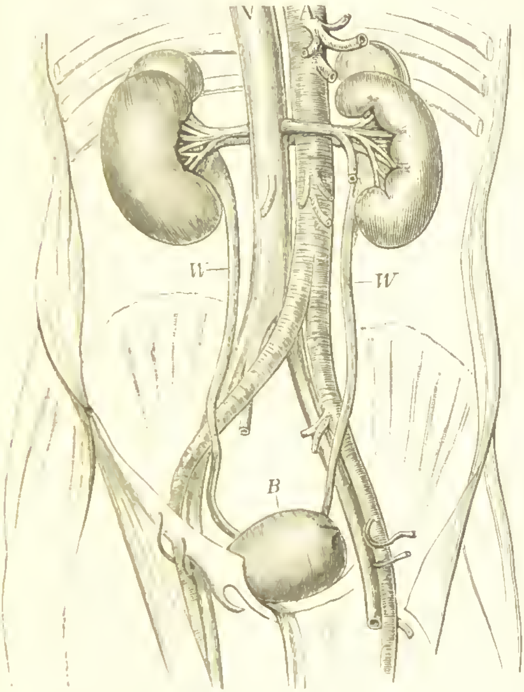


Fig. 75.—The Situation of the Kidneys.

A, aorta; V, vena cava; B, bladder; W, ureters. Branches of the aorta are seen going to the kidney, and veins from it are shown joining the vena cava.

between the part of the kidney containing the twisted tubes and that containing the straight tubes is easily made out with the naked eye, the former part appearing granular, and being called the **cortex,** while the central parts appear streaked, and are called the **medulla.** The distinction is represented in fig. 76, where it is evident that the medullary portion is formed of the pyramids whose bases rest on the cortex.

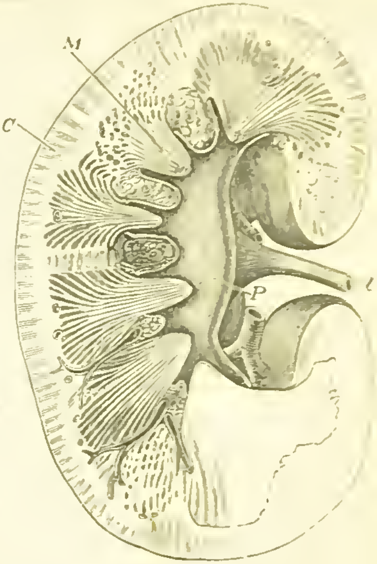
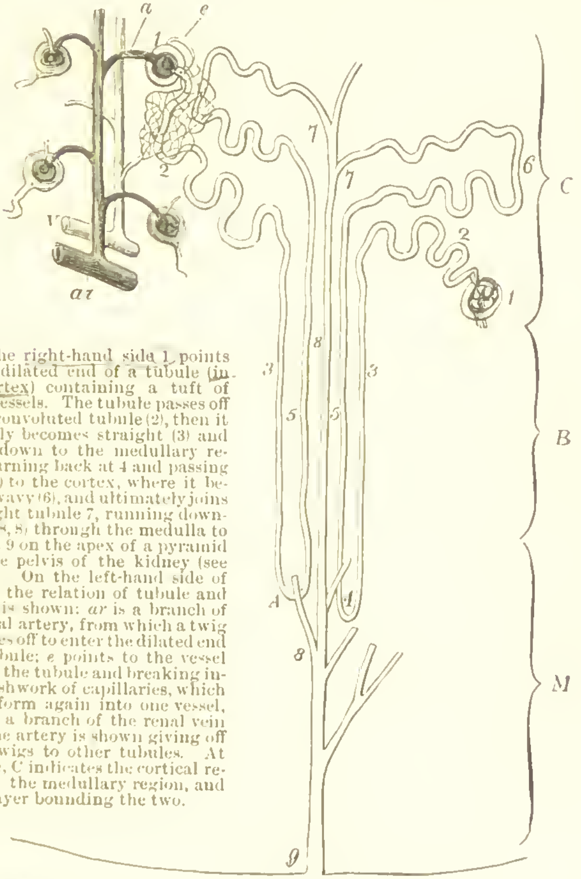


Fig. 76.—A Kidney opened in its length.

C, cortical portion; M, medullary portion; P, pelvis; U, ureter.

It is in the tubules that the urine is formed. The tubules all ultimately open by a group of mouths on the surface of the pyramids, so that the urine formed in them finds its way into the pelvis of the kidney, and thence down the ureter into the bladder.

The **tubuli uriniferi,** of which the bulk of the substance of the tissue is made up, are very fine tubes, about the $\frac{1}{600}$th of an inch in diameter. They run a very irregular course, undergoing various modifications in different stages. They begin in the cortical or outer portion of the kidney in a blind extremity which is dilated into a pouch or capsule. Into the capsule, as will be noted hereafter, a bundle of capillary blood-vessels projects. From this dilated extremity the tubule passes off by a narrow neck, and winds a very irregular course in the cortex, twisting and turning upon itself for some distance. This part of the tubule is called the **convoluted tubule.** Then, after a short portion in which the tube is more spiral than twisted, it suddenly contracts to a very narrow diameter and courses straight on towards the central or medullary part of the kidney into which it enters. But shortly after entering the medullary region it turns upon itself and proceeds, still in a



On the right-hand side 1 points to the dilated end of a tubule (in the cortex) containing a tuft of blood-vessels. The tubule passes off as the convoluted tubule (2), then it suddenly becomes straight (3) and passes down to the medullary region, turning back at 4 and passing back (5) to the cortex, where it becomes wavy (6), and ultimately joins a straight tubule 7, running downwards (8, 8) through the medulla to open at 9 on the apex of a pyramid into the pelvis of the kidney (see fig. 76). On the left-hand side of the fig. the relation of tubule and vessels is shown: *ar* is a branch of the renal artery, from which a twig (*a*) passes off to enter the dilated end of a tubule; *e* points to the vessel leaving the tubule and breaking into a meshwork of capillaries, which finally form again into one vessel, joining a branch of the renal vein (V). The artery is shown giving off other twigs to other tubules. At the side, C indicates the cortical region, M the medullary region, and B the layer bounding the two.

Fig. 77.—Diagrammatic View of the Tubules and Blood-vessels of the Kidney.

more or less straight direction, and as a very narrow tube, back into the cortex. This narrower portion that doubles on itself is called the **looped tubule** of Henle, after the observer who first described it. Ultimately the tubule mingles again with the convoluted tubules, and again becomes wider and wavy or spiral. This second spiral part of the tube leads into a wider straight tube which passes down through the cortex to the medulla. As it proceeds through the medulla it joins, now and again, similar tubes at acute angles or is joined by them, becoming thereby gradually wider until it opens on the surface of a pyramid. Fig. 77 gives, in a very diagrammatic way, a view of the passage of a tubule from its dilated extremity in the cortex to its mouth on the apex of a pyramid.

In the different parts of their course different diameters of the tubule have been noticed, and there are other corresponding differences. The tubules are formed of a delicate membrane whose inner surface is lined with cells. In some parts of the tube the cells are large and cloudy, presenting the appearances of cells engaged in the active work of secretion. In other parts they are small and insignificant, evidently not for secreting purposes, but simply to act as a lining to the tube. Fig. 78 shows the appearance of a cross section of a part of a convoluted tubule and of a part of such a tubule opened up, the cells being large and of the actively secreting kind.

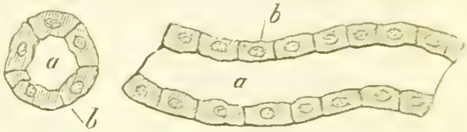


Fig. 78.—Very highly magnified view of cross and longitudinal section of a tubule. *b*, cells; *a*, channel of a tubule.

The Blood-vessel Arrangements of the Kidney.—It has been mentioned in passing that the dilated ends of the tubules contain bundles of fine blood-vessels. Each kidney receives an artery from the main arterial trunk—the aorta—as it passes through the abdomen. The artery after entering the kidney splits up into various branches, which penetrate into the substance of the kidney. They reach the junction between the cortex and medullary regions, from which twigs pass up between groups of the convoluted tubules towards the circumference of the kidney. On their way they give off branches. These branches penetrate the dilated ends of the tubules and immediately break up into a ball or tuft of capillaries, for which the end of the tubule serves as a covering or capsule. The ball of capillaries is called a **glomerulus**; and it, together with its capsule, forms a **Malpighian body** of the kidney. The capillaries ultimately reunite to form a small vessel which passes out of the capsule, and speedily thereafter that outgoing vessel gives rise to a number of capillary blood-vessels which ramify over the convoluted tubules, affording, we may suppose, nourishment to their cells. These capillaries are then gathered together to form a small vein which joins other veins till large veins are formed, whose junction forms one large vein which goes off from the kidney, carrying away the blood brought by the artery and pouring it into the vena cava (fig. 75). Other arterial twigs proceed from the junction of medulla and cortex into the region of the pyramids of straight tubes, over which they ramify, to end in veins as the others. The chief point to notice is that the vessel that enters the capsule—the **afferent vessel** (Latin *ad*, to, and *fero*, I carry)—gives rise, directly or indirectly, to two sets of capillaries, those of the glomerulus and those that proceed from the vessel that issues from the capsule — the **efferent vessel** (*ex*, out of, and *fero*). *The outgoing vessel is smaller than the ingoing;* and the significance of this will appear immediately. Fig. 79 represents a Malpighian body with its entering and issuing vessels, surrounded by the capsule, the blind end of a tubule. In fig. 77 is shown, in a diagrammatic way, the afferent vessel, arising from an arterial branch, forming the glomerulus, which ends in

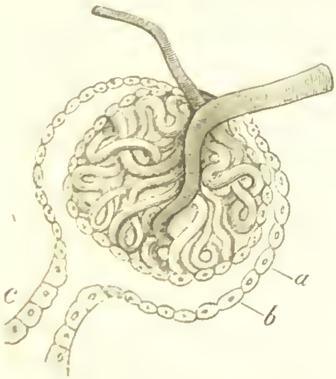


Fig 79.—Malpighian Body of Kidney, with its tuft of vessels.

a and *b*, cells of capsule formed of dilated end of tubule *c*. The wide vessel is the afferent; the narrow one is the efferent. Very largely magnified.

the efferent vessel, whose capillaries ramify over the convoluted tubes and end in a venous twig. In the Malpighian body the tuft of vessels is covered with a layer of flattened cells, so also is the inner surface of the capsule.

These details of structure show, to a great extent, how the kidney discharges its duties in separating waste matters from the blood, and what is the nature of the mechanism by which this is effected.

The Functions of the Kidney.—The business of the kidney is to separate certain substances from the blood which have gained access to it in its course through the body, and are the expression of the decompositions effected in the tissues by their activity. The chief of these substances removed by the kidney is urea, a solid crystalline body. But the excretion of the kidney is a fluid—the **urine**—in which urea and various other organic and inorganic substances are in solution. What is known of the structure of the kidney indicates that in the formation of the urine there are two processes at work. One process is performed in the Malpighian bodies. An artery enters the capsule of the body and immediately breaks up into a tuft of capillaries. Now the blood is always exerting considerable pressure on the walls of the vessels, and the capillary vessels are very thin-walled. One would at once conclude that fluid would ooze through the thin capillary walls and be received in the capsule. The capsule is the dilated end of a uriniferous tubule, so that the escaped liquid would find its way down the tubule, and so into the pelvis of the kidney, into which the tubule opens. As it collected in the pelvis it would flow into the ureter and so reach the bladder. In short, the structure of the Malpighian body suggests that it is a sort of filter, the filter being formed by the thin walls of the blood-vessels of the tuft with the fine layer of cells which covers them, having on one side of it blood under pressure and on the other side the cavity of the capsule (see fig. 79). As the blood streams through the capillary tuft, fluid filters from it into the capsule, and the greater the pressure of the blood the more fluid will be passed through. Force and confirmation are given to this view by the fact that the vessel, which the capillaries of the Malpighian body form, and which leaves the capsule, is narrower than the entering artery. The supply pipe is larger than the escape pipe; blood passes into the Malpighian body more readily than it escapes from it. Consequently the blood in the capillaries will be at greater than usual pressure, and filtration of liquid from it will be encouraged. The structure of the apparatus, therefore, suggests that one part of the process of urine formation consists in the separation from the blood by filtration of certain of its fluid constituents. This does not, however, appear to be all. As soon as the blood has passed out of the Malpighian bodies in the efferent vessel it is distributed over the convoluted tubules by fine capillary blood-vessels into which the outgoing vessel breaks up (see fig. 77). Now the convoluted tubules consist of a very delicate wall lined within by large active cells (fig. 78), and blood is brought in thin-walled vessels into intimate connection with the tubes. These are just the conditions of secretion. The active cells of the tubules are separated from nourishing blood only by the thin walls of the tubes and vessels. It is therefore probable that the cells separate certain substances from the blood, which they work up and then pass into the tubule among the fluid filtered into the capsule and finding its way down towards the ureter. It has been, therefore, concluded that the process of formation of urine consists of two parts—(1) of a separation of fluid parts of the blood *by filtration* in the Malpighian tufts, and (2) of a separation *by active cells* from the blood of probably more solid substances, which are added to the filtered fluid in its course down the tubules.

The secretion of the kidney may, therefore, be modified in two ways: (1) by influences affecting the pressure of blood in the vessels of the glomerular tuft, and (2) by influences acting upon the cells of the tubules. Anything which raises the blood-pressure in the vessels will increase the quantity of fluid filtering through, that is, will increase the watery portion of the urine without necessarily adding to its solids. The urine, that is to say, will be more abundant but more watery. Conversely anything which lowers the pressure of blood in the vessels of the Malpighian bodies will diminish the watery portion without necessarily affecting the solids, that is to say, the urine will be scanty but more concentrated. Now on page 172 it has been shown that the nervous system, by vasomotor nerves, regulates blood-pressure. Some nervous influence, therefore, by determining a greater flow of blood to the kidney, or otherwise increasing the blood-pressure, will cause a larger flow of clear watery urine. Such is the effect of fear and other emotions. Again, in winter the cold external atmosphere causes contraction of the vessels of the skin, drives the blood to the deeper organs, and increases the pressure there, so that while there is diminished perspiration there is increased flow of urine, which contains a smaller than usual percentage of solids, and is much lighter than usual because of its dilution. A hot external atmosphere has a reverse effect. The heat determines a greater than ordinary flow of blood through the vessels of the skin, the blood is thus withdrawn from the deeper organs, and not only is the blood-pressure in the kidneys diminished, but the total quantity of blood flowing through them in a given time is much lessened. Consequently the urine is scanty, but it contains a higher than usual percentage of solids, and the concentration is also indicated by the greatly increased depth of colour. Certain drugs, by increasing the force of the heart's action, raise the blood-pressure and so increase the flow. But in the second place, drugs in the blood, or certain kinds of drink or food, may stimulate, or the reverse, the secretory activity of the kidney cells, and so increase or diminish the solids excreted without affecting the quantity of water.

The Excretion of the Kidney—the Urine. The characters of the healthy urine are well defined: and they undergo marked alterations in disease.

Urine when freshly passed is of an amber **colour**, clear and transparent, and with a peculiar aromatic **odour** and of slightly acid **reaction.**

Its **specific gravity** is usually about 1020.

The **quantity** passed in 24 hours by a healthy adult man is between 50 and 60 fluid ounces. It varies not only according to the quantity of water taken in by the mouth, but according to the external temperature and the amount of exercise. The kidneys and skin co-operate to this extent, that if much water is removed by the skin as sweat, as in warm weather and after exercise, less is expelled by the kidneys. In cold weather the skin is less active, and a greater quantity of water will be produced by the kidneys. Nervous influences also affect the quantity. Thus after hysterical attacks a large quantity of clear urine is often passed.

Its **chemical constitution** is shown in the following table:—

	In 1000 parts.	Quantity in 24 hours varying between
Water	958	
Solids	42	
The solid constituents are—		
Urea	23·3	400 to 600 grains.
Uric acid	0·5	5 „ 12 „
Chloride of sodium (common salt)	11·0	150 „ 200 „
Phosphoric acid	2·3	48 „ 54 „
Phosphates of lime and magnesia	0·8	11 „ 16 „
Sulphuric acid	1·3	23 „ 38 „
Ammonia	0·4	9 „
Free acid	2·0	30 „ 60 „
Various other substances — kreatinin, hippuric acid, &c., in very small amount.		

The average quantity in 24 hours is of water 52 ounces, of solids 840 to 920 grains.

Gases, principally carbonic acid gas, nitrogen and oxygen being in very small quantity, are also contained in urine to the amount of nearly 16 per cent.

The solid constituents consist of two classes of substances: (1) inorganic salts, namely, common salt (chloride of sodium), sulphates, and phosphates, and (2) organic bodies, bodies containing nitrogen, namely, urea, uric acid, hippuric acid, kreatinin, &c. It is instructive to observe the sources of these substances. Chlorides occur in all the fluids of the body; sulphates arise from the decomposition of albuminous bodies; and phosphates have as their source albuminous bodies, the phosphates existing in bone, and phosphorus present in nervous structures.

The chief constituents, however, are the nitrogenous, urea and uric acid, the former specially, of which a large amount is excreted, as indicated in the table. Urea contains the four elements, nitrogen, hydrogen, oxygen, and carbon, nitrogen forming half its weight. While, therefore, the lungs expel from the body carbonic acid in particular, the kidneys expel nitrogen. Both of these substances express decompositions going on in the body, the carbonic acid being the expression of the breaking down of starch, sugars, fats, and albumin also, while urea and uric acid are the products of the decompositions of those nitrogenous bodies only, of which albumin is the type. The quantity of urea is always increased by a diet rich in albuminous food-stuffs. It is the last stage in the oxidation process which such food-stuffs undergo in their transit through the body (see p. 87). Uric acid probably represents a stage in the oxidation of nitrogenous bodies not so far advanced as urea. In human urine its quantity is very small (see table). In fevers and other abnormal states of body its quantity is greatly increased, and since it is more easily dissolved in hot solutions than in cold, when the urine cools it becomes deposited in the form of a brick-red precipitate, making the urine muddy. When in excessive quantity, as in rheumatism and gout, it may form deposits in kidney or bladder, leading to the production of "stone," and in gout it is deposited in the fibrous structures around joints in the shape of chalk stones.

Some colouring matter is also present in urine.

Unusual constituents of urine are albumin, sugar, bile, and blood. When albumin is present in urine it, as a rule, indicates some disease of the kidney, to which the term **albuminuria** has been applied. The presence of sugar indicates the disease **diabetes.** Bile is another unusual constituent of urine, appearing in jaundice. The presence of blood gives a smoky colour to urine.

THE URETER AND BLADDER.

The **Ureter** is the tube which leads from the kidney to the bladder, and is shown in fig. 75. It enters the bladder at the lower part, behind and to the side of the middle line. In length it is from 16 to 18 inches, and is about the size of a goose-quill. It is formed of an outer fibrous coat, a middle muscular coat, and an inner mucous lining with stratified squamous epithelium (p. 31) on its free surface. To its walls blood-vessels and nerves are distributed. Its channel is narrow, and it can be easily understood that if a stone has been formed in the kidney, and gets forced into the ureter, its passage down that channel will be accompanied by excruciating pain. The urine is conveyed from the kidney to the bladder by a wave of contraction passing along the ureters from the kidney to the bladder. It reaches the bladder not in a constant stream, nor yet in occasional gushes, but drop by drop, so that it gradually accumulates there.

The ureters open obliquely into the bladder, so that the urine finds its way into the bladder easily, but could not be readily forced up the tube from the bladder.

The **Bladder** is situated in the pelvis (p. 51, and fig. 75, p. 215) in front of the termination of the large bowel. Its front face is in contact with the inner surface of the junction of the pubic bones (*sp*, fig. 27, p. 51); and when full the top of the bladder projects above the bone. It is in this position that pain is felt when the bladder is strained by overfulness. When full the bladder is pear-shaped, when empty it is collapsed and lies low in the pelvis. It consists of three coats, an outer fibrous layer, a middle of muscle, of the unstriped variety, whose fibres run in bundles forming an irregular network, and an inner mucous layer with stratified squamous epithelium like the ureter. The peritoneum (p. 73) also in par covers the organ. From the small end of the bladder a canal passes—the **urethra**, into which the bladder opens, and by which it is put in communication with the outside. The narrow end is called the neck of the bladder, and is surrounded, at the junction with the urethra, by a special bundle of muscular fibres, called the **sphincter of the bladder.** Urine cannot escape from the bladder unless the guard of the sphincter is relaxed.

The **functions** of the bladder are to collect and retain the urine from the kidneys until a certain quantity accumulates, and then to expel it in a stream. The urine enters its receptacle from the ureters drop by drop, and when the bladder becomes distended its emptying is effected apparently by a reflex nervous act (p. 246). An impression passes to a centre low down in the spinal cord. An impulse is thus originated by which the sphincter muscle is relaxed and the muscular walls of the bladder caused to contract. The channel being open, the contraction of the walls exerts pressure on the contained fluid which is thus expelled. Nervous diseases may affect the act of expulsion. The tone of the sphincter may be lost, so that the urine cannot be retained, or the bladder may be paralysed so that the fluid cannot be driven out. To this extent the action is voluntary, in that the result of the process may, for a time, be prevented by the will, or may be aided by voluntary effort producing contraction of the abdominal walls, and thus exerting pressure on the bladder.

CHAPTER X.—THE SKIN, HAIR, AND NAILS.

The **Skin** occupies an important position as an organ of the body. It is a blood-purifying organ in as true a sense as the lungs or kidneys are, while it also performs other very important duties. It is not, therefore, merely a protective organ as is too generally supposed. It does form an external covering for the deeper tissues over the whole body, and that its protection is very necessary and efficient everyone knows who has experienced the pain produced by the contact of almost anything with a part of the body from which the top skin has been removed; but in some respects this is the least valuable, though the most apparent, of the functions it discharges.

Its **structure** is remarkably complex. The skin consists of a deep layer called the **dermis, corium,** or **true skin** (*cutis vera*), and of a superficial layer—the **epidermis** (Greek *epi*, upon, and *derma*, the skin), **cuticle,** or **scarf skin** (*a*, fig. 80). The true skin (*c*) consists of fibrous tissue, the bundles of which form a felted interlacement. It lies upon a bed of fatty tissue (*c′ d*, fig. 80) which fills up the inequalities of the surface on which the skin rests. Groups of the fat cells of this tissue also abound in the deepest layers of the true skin. Pervading the fibrous tissue is also an abundance of fibres of the elastic sort (p. 35), which confer elasticity on the skin. The true skin is very vascular, that is, is richly supplied with blood-vessels, so that when cut it bleeds; and nerve-fibres are likewise disposed in it, conferring sensibility. The surface of the true skin is thrown into a series of elevations, papillæ, or finger-like prominences (*b*, fig. 80) which are specially rich in capillary blood-vessels and nerve endings, and which are thus particularly vascular and sensitive. Above the true skin is the scarf skin, the projections of the former fitting into excavations in the latter. The epidermis, however, is composed entirely of cells, and is quite devoid of blood-vessels or nerves, so that it may be cut without bleeding or pain. There are

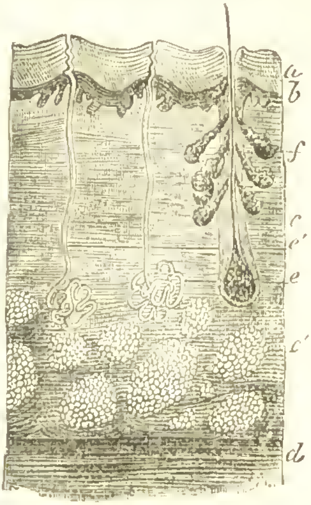


Fig. 80.—The Structure of the Skin.

several layers of cells, and the shape of the cells alters from the deep parts upwards. The cells directly lining the surface of the true skin and the papillæ are columnar and nucleated. They are soft and active cells, and clothing the papillæ are several layers of them. In the layers nearer the surface the cells lose their columnar shape and become more flattened. They also gradually become less soft and more horny, until towards the surface they are flattened and scale-like. The surface scales are continually being thrown or rubbed off, and their places are supplied by deeper cells which reach the surface by growth from below. New cells are continually being produced in the deep layer in contact with the true skin; and as they are formed they push upwards the already existing cells. So that cells originally active and columnar gradually pass upwards, becoming horny, till they are finally cast off. The fine white dust that one may scrape off the skin consists of these horny scales.

It is in the deep and active layers, called the **rete mucosum**, of the epidermis that colouring matters are present, which give the hue to the skin. For example, in dark races black pigment is present in these cells. The epidermis is thickest over the parts exposed to greatest pressure or friction, securing protection to the sensitive true skin below. (See also fig. on p. 297.)

At the orifices of the body the skin passes into mucous membrane, the structure of the two being practically identical, the differences being merely in the thinness of the epidermal covering of the mucous membrane and the increased supply of blood to the membrane.

Glands of the Skin.—The special glands of the skin are the **sudoriparous** (*e*, fig. 80) or **sweat glands** (Latin *sudor*, sweat, and *pario*, to bring forth). They are tubular glands. Deep in the substance of the true skin, or in the fatty tissue beneath it, the tube is coiled up into a sort of ball. From the coil the tube (*e′*) passes upwards through the true skin, following a wavy course, till it reaches the epidermis, which it penetrates in a spiral manner till it opens on the surface. Two of such glands are shown in fig. 80. The tubes consist of delicate membranous walls lined within by cells. The coiled part of the gland is surrounded by a dense network of fine blood-vessels, and thus the cells of the gland are separated from the blood by only a very fine membranous partition, and can draw from it what supplies they need for their particular work.

It is estimated that the total number of sweat glands in the human skin is over two millions. They are not, however, equally distributed over the body. They are fewest in the back and neck, where it is estimated there are on an average 400 to the square inch. They are in greatest number in the skin of the palm of the hand, where they amount to nearly 3000 in each square inch, according to Erasmus Wilson, 3528. Their openings occur on the ridges into which the skin is there thrown, and may be made out by a hand lens. Next to the palm of the hand they occur in greatest number in the sole of the foot, next on the back of the hand and foot, and the smallest number is that already noted in the skin of the back. The length of a tube, when fully straightened out, is about $\frac{1}{4}$ inch; so that, according to Sir E. Wilson, in one square inch of skin from the palm of the hand there is a length of sweat tube equal to 73½ feet. Estimating the number of glands in the body to be between two and three millions, the total length of tube devoted to the secretion of sweat would be about *10 miles.* According to Erasmus Wilson's estimate it amounts to even *28 miles.*

Hair.—Hairs and nails are originally derived from the epidermis, and are essentially cellular structures. A hair is formed by a folding or dipping inwards of the skin. A depression or furrow is thus formed, the inner walls of the depression consisting of the infolded epidermis. The depression takes the shape of a sac and is called the **hair sac** or **hair follicle.** At the bottom of the follicle is an enlarged papilla of the true skin (*c*, fig. 81) pushed downwards by the folding-in process. Like the other papillæ of the skin it is covered with the active cells of the deep layer of the epidermis, which form a bulbous enlargement over the papilla, that is, the root of the hair. As the cells in direct contact with the papilla grow and multiply those above them are pushed upwards to make room for them, and owing to the shape of the hair sac the cells become packed together so as to form a cylinder or stem, which finally, as the growth from below goes on, is pushed out beyond the skin as the shaft of the hair. A hair thus consists of a peculiar arrangement of the cells covering the true skin. So closely are the cells packed to form the cylinder that a fibrous appearance is presented, except in the centre of the hair— the medulla —where the cells still retain their shape, and make the hair appear different in the centre from the circumference. The hair is thus *not a tube but a solid rod* composed of cells packed tightly at the circumference and loosely in the centre. Sometimes little spaces exist in the centre owing to absorption of cells, and the spaces are filled with air, giving in some parts the appearance of a tube, when the hair is examined under the microscope. The different colours of hair are due to pigment present in the cementing substance between the cells as well as in the cells themselves.

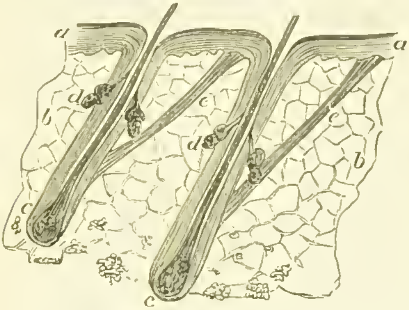


Fig. 81.—Hair, Hair Follicles and Glands.

a, epidermis; *b*, true skin; *c*, hair bulb; *d*, sebaceous glands; *e*, muscle attached to hair sac.

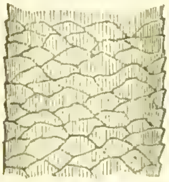


Fig. 82.

Fig. 82 shows the appearance under the microscope of a hair, the cells overlapping one another like tiles on a roof.

Glands of Hair.—Opening off from each hair sac are one or two glands (*f*, fig. 80), the **sebaceous** glands (Latin *sebum*, tallow). They are also shown in fig. 81, *d*, and consist of groups of minute pouches lined with cells, which produce an oily material to lubricate the hair and skin. Connected with each hair sac, especially if of a good size, is a bundle of involuntary muscular fibres (*e*, fig. 81). The bundle passes in such a direction that, when it contracts, the hair sac, which is placed obliquely in the skin, is caused to become more upright, and thus the hair is made "to stand on end." It is this that causes the appearance of "goose's skin."

A **Nail** is also a compact mass of epidermal cells. At the bottom of a fold on the skin is the root of the nail, at which growth takes place by multiplication of cells. The nail is thus continually pushed forward by the growth behind. The bed on which the nail rests, and from which it also receives additions, is formed by numerous papillæ of the true skin.

Just as in man hair and nails are modified epidermal structures, so the feathers of birds, and the claws of animals, are formed from the surface layers of the skin.

Functions of the Skin.—Manifestly the skin *covers in and protects* the more delicate structures that lie beneath it. This it does by means of the horny and insensitive epidermis; for everyone knows that, if by an injury the cuticle is torn off, the uncovered true skin is keenly sensitive to the slightest contact with any foreign body, and to heat and cold. The epidermis also protects from the absorption of poisons, for one may handle with impunity, when the skin is whole, substances which, gaining access by the smallest wound, might cause serious injury. The skin, however, ranks as *an excretory organ* of importance. Its excretion is called sweat, and is the product of the sudoriparous glands. In addition the sebaceous glands secrete an oily fluid useful for lubrication. Moreover by means of the sweat the skin performs the function of regulating the temperature of the body.

The **sweat or perspiration** is a colourless transparent fluid, consisting chiefly of water, but containing a small quantity of saline material and traces of urea, and being of acid reaction. In some parts of the body, and especially in the arm-pits, the glands secrete a substance having a peculiar smell. It would seem also that some carbonic acid gas passes off by the skin, but not more than $\frac{1}{50}$th of what escapes by the lungs. In ordinary circumstances the sweat passes off from the skin as vapour as fast as it reaches the surface. One would readily conclude, therefore, that usually the skin is not active. This is not so. On an average the quantity of water that escapes from the skin as vapour is about 2 lbs. daily. If very active exercise be engaged in, or if the body be exposed to great external warmth, particularly when the external air is moist, the sweat becomes more abundant, and, unable to pass off quickly enough, collects on the surface in drops. A distinction is, therefore, drawn between **insensible perspiration**, the perspiration that passes from the skin unseen as vapour, and **sensible perspiration**, the sweat that collects on the surface. The distinction is worth noticing, since water is continually being lost from the surface of the body, though at times it is quite apparent, and at other times not so. A man's weight may be reduced several pounds in an hour by loss through perspiration alone. To some extent this may explain the weakening effect produced by excessive sweating in the course of some diseases, for example the night-sweats of consumption.

It is in the coiled part of the sudoriparous gland that the sweat is produced. The blood that surrounds the coil in capillary vessels is in intimate connection with the cells of the gland, and it is from the blood that the cells separate the materials that form the perspiration. It is thus apparent that the greater the quantity of blood flowing to the skin the more sweat is likely to be formed. The blood-vessels of the skin, like the blood-vessels of other parts of the body, are under the control of the nervous system, by which their diameter is regulated. If the nervous control is removed the blood-vessels dilate, more blood flows through them, and more raw material is brought to the glands. In other ways the blood-vessels may become more fully charged with blood than usual.

External warmth relaxes the skin and the vessels; there is thus a determination of blood to the skin and increased perspiration. On the other hand external cold causes the skin and vessels to contract, diminishes the supply of blood, and lessens the amount of sweat. By such a process as this the skin is able to discharge a third function, that of **regulating the temperature of the body.**

The transition of a liquid to the state of vapour is always accompanied by a loss of heat. Heat is necessary, that is to say, to convert a liquid into a vapour. Any liquid that very quickly evaporates produces, when placed on the skin, a marked sense of coldness, because the heat necessary to transform the liquid into vapour has been drawn from the skin, and withdrawn quickly. Even so, every particle of sweat that reaches the mouth of a sweat gland and passes off into the air carries with it a certain quantity of heat from the body, and cools the body by that amount. It is this that makes one so readily feel chilly after excessive sweating, the evaporation of a large quantity of sweat rapidly cooling the surface. Now, if the atmosphere be very warm, a greater quantity of sweat will be produced, as we have seen, and its evaporation will tend to prevent the heat of the body rising. Whereas, if the atmosphere is cold, much less sweat is produced, and the loss of heat from the body is greatly lessened, and its temperature prevented from falling. Thus the skin greatly aids in maintaining an average heat of the body, and in preventing rises and falls of its temperature with every variation of the external atmosphere.

It would seem also as if the nervous system had some direct action on the sweat glands. Fear or other strong emotion often causes sweat to break over the skin even while the surface is very pale and the quantity of blood diminished. Cold sweats are frequent in the extreme depression that precedes some forms of sickness or fainting. It is probable that such outbursts of sweat are due to some nervous influence accompanying the general condition and acting directly on the sweat glands.

Many drugs influence the process of sweating either by increasing the amount or by diminishing it. Thus opium causes profuse sweating, while atropine, the active principle of belladona, is capable of completely arresting it.

The reason for giving medicine to excite sweating during the course of some fevers is plain. By promoting the activity of the skin they tend to reduce the heat, and, moreover, by increasing the quantity of material separated from the blood they widen a channel by which morbid stuff that may exist in the blood and be the cause of the disturbance may be swept out.

Some relationship exists between the skin and kidneys. In cold weather, when the skin is less active, a large quantity of water is passed off by the kidneys, while in warm weather, or under circumstances producing great activity of the skin, the quantity of water separated by the kidneys is proportionately diminished. This is a point of great importance. It indicates that, when disease of the kidneys is present, these organs may be relieved to a considerable extent and their labour lessened by any means which excite perspiration.

If the skin be covered over by varnish, so that its functions are completely arrested, death speedily results. The reason is not known, though many explanations of the circumstance have been offered. After varnishing, the bodily heat falls very rapidly, due, it has been said, to the blood-vessels of the skin becoming very wide, permitting a large flow of blood to the surface and rapid cooling in consequence. In animals that have been varnished death has been delayed for a considerable time by wrapping them in cotton wool, and thus hindering the great loss of heat, or by placing them in some warm place to maintain the temperature. This, however, does not seem to explain all the effects of varnishing the skin. Symptoms of blood poisoning arise. The retention of poisonous matters in the blood, owing to the activity of the skin being set aside, would explain such symptoms.

Tarring and feathering, the punishment of mob-law in some parts of America, have effects similar to those of varnishing the skin, and cause a painful death after some time. The hot tar, poured over the body, so enters and closes up the pores of the skin, that it is practically an impossibility to remove it.

Finally, the skin seems capable of **absorbing matters** to which it is freely exposed, and of passing them onwards into the blood. Fluids in contact with the skin, and solid substances rubbed into it, may be absorbed. Thus cases are on record where persons have gained weight by exposure to a moist atmosphere, or by immersion in a bath. Sailors, deprived of fresh water, have been able to allay their thirst by keeping their clothes soaked in salt water. Mercury and other ointments rubbed into the skin are capable of acting on the system, apparently because particles gain entrance to the lymphatics. The extent to which absorption occurs through the sound skin, however, is not great. Even where vigorous rubbing is performed to force the particles into the mouths of the glands the absorption is limited. But from parts where the scarf-skin has been removed, various substances may be picked up and passed rapidly into the blood. Sometimes, therefore, where it is thought desirable to act through the skin, a small blister is applied, and the substance—morphia powder, for example—dusted over the raw surface.

The part played by the skin in touch will be considered in the chapter on the organs of sense.

These considerations as to the functions of the skin ought to render it apparent that the skin is a very important organ of the body. It is not, however, generally viewed in this light. At least it very often does not receive the care and attention which, as such, it deserves. It will be apparent that the minute openings of the sweat glands—the pores of the skin as they are called—may be easily blocked by worn-out cells of the cuticle or by materials deposited by the drying of the sweat, and that, to keep the skin free and active, constant cleansing is necessary. If systematic cleansing of the surface of the body is not practised, not only will the skin fail to separate from the blood the waste products it ought to expel from the body, but more labour will be thrown on other organs, and specially, as noted above, on the kidneys. to counteract its inefficiency. Thus uncleanliness may not only cause disease in the skin, but may help to excite disease in other parts.

CHAPTER XI.—NUTRITION. THE BALANCE OF WASTE AND REPAIR IN THE BODY.

It is now desirable to sum up briefly in one connected statement the bearing of the facts that have been narrated in previous chapters.

The human body is to be regarded as a machine for doing certain work—just as a steam-engine is a machine for doing work. Now, a steam-engine is built up of certain materials in a particular way, dependent upon the work it has to perform. The energy required to move its wheels with force sufficient to effect its purpose, is derived from the burning of fuel in its furnace to raise a sufficient pressure of steam. It requires daily attention to maintain its parts in good condition, and to remove ashes from its furnace and other waste matters which would impair its efficiency. The human body consists of a framework of bones clothed with muscles. padded and protected by fat, and covered with skin. The muscles are so placed that when they contract or shorten they move the bones, and thus physical work is accomplished. It performs other than physical work—the various mental operations that go on in the brain being as much work as manual labour is—the nervous structure being, in a sense, as much a piece of machinery for the turning out of ideas, &c., as a loom is a piece of machinery for the manufacture of cloth. The human machine suffers from tear and wear, which must be repaired, and it also needs energy for its work. To repair this tear and wear, and to supply energy to the different parts of the machine, a nourishing fluid, the blood, is distributed throughout the body. Channels are needed along which it may be conveyed—the blood-vessels; and a force-pump to drive it along the channels—the heart. When this fluid reaches the part of the body, the tissue or organ where the tear and wear occurs, and where the energy is expended, it is distributed in an infinite number of tiny streams in the part; and the streams are conducted along channels so thin-walled that the fluid can ooze out to supply the part, and the part can select the quantity or special ingredients of the fluid it requires. Thus the blood is continually being drained of its repairing and energy-producing material. Its loss must constantly be made good. It is, therefore, necessary to introduce into the body at intervals material to replace that used up. This is the purpose of food. But food is not, in the form in which it is taken, in a proper condition to enter the blood, to make up what it has lost. It must be worked up into proper condition, and for this purpose it undergoes the elaborate process of preparation which is included under the term digestion, after which it is passed into the blood by the process of absorption. The true sense of the word nutrition, then, does not imply this process of elaboration—that is only a preliminary to nutrition—but it properly refers to the process by which the blood comes into contact with the elements of the tissues, and by which they obtain from it what they need to repair their waste and supply their needed energy. Healthy nutrition, therefore, depends upon the blood being in a condition to supply the tissues with the materials they need in proper quantity, and upon the tissues being able to make use of the supply when it is brought to them—that is, upon (1) a proper quality of blood, (2) a proper quantity of blood, and (3) a proper condition of the tissues themselves.

The tissues, then, use the blood to repair any of their broken-down structure, and to derive from it energy. Now, the process by which the tissues liberate energy from the material brought to them by the blood is to a large extent, so far as is known, a chemical process. It is a process akin to that by which energy is obtained in a steam-engine from coal. The coal undergoes burning or combustion, and in the process the energy locked up in the coal is released. Combustion consists in the union of a substance with oxygen. In the case of coal it is the carbon of the coal that unites with oxygen, producing heat, and consequently energy. In the case of the steam-engine the oxygen is derived from the atmosphere. Now, in the tissues a similar process goes on, the material derived from the blood undergoes combustion, it unites with oxygen, and energy is thus liberated. The oxygen must be obtained also from the blood. It is by means of the red corpuscles of the blood, mainly, that the oxygen is conveyed to the tissues. The blood being thus continually deprived of oxygen must have that source of loss made up again. To some extent oxygen is supplied in the food, but not in sufficient quantity. To effect this the lungs are provided, and the blood coming to them with lessened stores of oxygen, renews its supply as it passes through them. But the combustion going on in the tissues implies the production of waste materials, just as the burning of coal in a furnace implies the production of waste—ashes, smoke, &c., which must be got rid of, and must not be allowed to accumulate. To a large extent the waste is poured directly into the blood; to a certain extent it is picked up, along with excess of material that may have escaped from the blood, by special channels (lymphatics) as lymph, and is in the end returned to the blood. The blood must be rid of the waste quickly. For this purpose special apparatus is provided. the lungs removing the products of the combustion of carbonaceous substances, namely, carbonic acid gas and water, the kidneys removing the products of the combustion of nitrogenous bodies in the shape of urea, &c., the skin separating water, and the liver other substances. The waste matters removed by the bowel are mainly useless matters introduced in the food, and not to any great extent the products of combustion going on in the tissues.

This bare statement gives a general idea of the principles on which the body is built up, viewing it as a machine for performing work, and of the relationship of its various parts. It remains to be added that the whole machinery is kept working harmoniously by the superintendence of the nervous system.

From this point of view the healthy full-grown human being takes in daily a certain quantity of liquid and solid food, and a certain quantity of oxygen, and daily casts out a certain amount of waste. By the changes the liquid and solid food and oxygen undergo in passing through the body, before they reappear in the form of waste, there is liberated a certain quantity of heat and energy in the shape of work. There is daily, that is to say, a certain amount of income and a certain amount of expenditure. If the two are equal to one another there is a balance, and the body at the close of each day is in the same condition as at its commencement. If the income exceeds the expenditure some material must have been stored up in the body, and the body will show a gain in weight; if the expenditure exceeds the income, the extra expenditure must have been met from some store already in the body or at the cost of the tissues themselves, and the body will have lost in weight.

A balance-sheet of daily income and expenditure of an average healthy adult may thus be constructed as shown in the following table. We may first tabulate the sources of gain and of loss to the body as a whole.

Sources of Gain.

The Alimentary Canal:

Food as (1) *Proteids*, made up of carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus;
(2) *Carbo-hydrates*, that is, sugars, starches, made up of carbon, hydrogen, and oxygen;
(3) *Fats*, made up of carbon, hydrogen, and oxygen;
(4) *Saline materials;*
(5) *Water*, made up of hydrogen and oxygen.

The Lungs:

Oxygen.

Sources of Loss.

The Alimentary Canal:

Refuse of food mainly, but also some waste cast off from the liver.

The Lungs:

Carbonic acid gas, made up of carbon and oxygen;
Water.

The Kidneys:

Urea, made up of carbon, hydrogen, oxygen, and nitrogen;
Water;
Salts.

The Skin:

Water;
Carbonic acid gas.

The next table shows the amount of gain and loss in each case.

BALANCE OF INCOME AND EXPENDITURE IN THE BODY (CHURCH).

Income.

	Avoirdupois.					
	lbs.	oz.	grains.	lbs.	oz.	grs.
Oxygen, in starch, fat, and proteids taken as food,	0	7	370	= 2	2	47
,, in air breathed, ...	1	10	115			
Carbon in starch, fat, and proteids taken as food, ...				0	9	400
Hydrogen in starch, fat, and proteids taken as food, ...				0	1	170
Nitrogen in proteids taken as food, ...				0	0	291
Saline materials in food, ...				0	1	57
Water, ...				5	8	320
Total daily income, ...				8	7	410

Expenditure.

	lbs.	oz.	grains.	lbs.	oz.	grs.
Oxygen in carbonic acid gas given out by lungs and skin,	1	7	436	= 2	2	47
,, in material from bowel and kidney, ..	0	0	357			
,, in water formed in the body, ...	0	9	130			
Carbon in carbonic acid gas given out by lungs and skin,	0	8	360	= 0	9	400
,, in material given out by bowel and kidney,	0	1	40			
Hydrogen given out in water formed in body and by lungs and skin, ...	0	1	70	= 0	1	170
,, in material given out by bowel and kidney,	0	0	100			
Nitrogen, as urea, &c., given out by kidney, ..	0	0	245	= 0	0	291
,, as waste expelled from bowel, ..	0	0	46			
Saline material expelled by kidneys and skin, ...				0	1	57
Water given out by kidneys, lungs, skin, and bowel, in addition to that formed in the body, ...				5	8	320
Total daily expenditure, ...				8	7	410

In the course of combustion, as we have said, by which the food is broken down from the complex state in which it enters the body into the simple conditions in which it is cast out of the body, energy is liberated in the form of heat and mechanical work. The amount of energy thus liberated is expressed by saying that it is sufficient to raise 3950 tons weight 1 foot high.

Engineers seek to have all the energy transformed into mechanical work, and none wasted in heating the engine. This is, of course, impossible of attainment, the best constructed steam-engine being able to yield only 8 to 10 per cent of the energy as mechanical work, the rest being wasted as heat. In the human body, however, about 25 per cent of the total energy liberated appears as mechanical work. In the case of the human body, however, heat is necessary, and not injurious as in the engine. The heat of the body must be maintained at about 98°·4 Fahrenheit.

The heat of the body, then, is maintained mainly by the oxidation or combustion process going on in the tissues, and to a feeble extent by mechanical actions, the friction of the blood in the vessels, movements of muscles, &c. Heat is lost in the body by raising the temperature of food and drink taken into the alimentary canal, and of air taken into the lungs, by contact with the colder external atmosphere, and by evaporation of sweat (see p. 233). The important point to notice is the fact that, in spite of great variations of the external temperature, a pretty uniform bodily temperature is maintained; that is to say, a continual balance between gain and loss of heat is maintained. This is effected mainly by the skin, as explained on p. 233; and the influence of the nervous system in regulating the diameter of blood-vessels and the distribution of blood to the surface, by means of vaso-motor nerves, is all-important.

CHAPTER XII.—THE NERVOUS SYSTEM.

No matter how complicated a nervous structure, such as that of man may appear to be, it is found to consist essentially of two, and only two elements, **nerve-cells** and **nerve-fibres.** The cells and fibres are combined and associated in various ways and are imbedded in and supported by fine connective tissue so as to form a consistent structure. The nervous tissue so formed is protected by membranes, and receives a rich supply of blood for its continued nourishment and growth, channels also being provided for the removal of its waste substances.

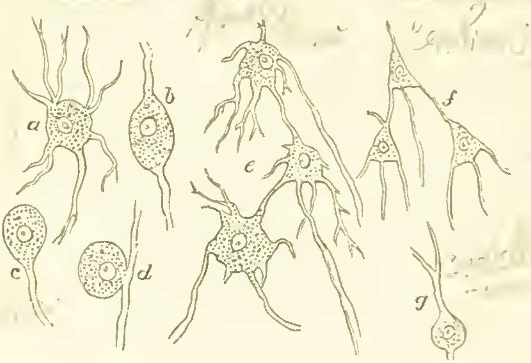


Fig. 83.—Various Forms of Nerve-cells. *b* and *d* from ganglia on posterior roots of spinal nerves. For other references see text.

Nerve-cells have a general resemblance under the microscope to other cells. They vary in size from $\frac{1}{5000}$ to $\frac{1}{400}$ of an inch. They consist of masses of granular-looking material—protoplasm—and contain a nucleus and nucleolus (see CELLS, p. 26), but have no cell-wall. Processes or poles pass from the corpuscle or cell, branching outwards. There are various kinds of nerve corpuscles, the main differences being in the shape of the cells, and in the number of processes given off from them. Some cells give off two, others many processes. One kind of cell is characteristic of one part of the nervous system. Thus in fig. 83 *a* and *e* show the appearances of cells found in the spinal marrow. They are large, irregular masses of protoplasm, and give off many poles or processes, and are accordingly called **multipolar.** In the same figure *f* represents three cells from the large brain (cerebrum). They are triangular in shape, and give off a process from each angle, and another from the centre of the base of the cell. They are called **pyramidal nerve-cells** from their shape, and sometimes **tripolar** that is, with three poles, though, as we see, they may have four poles. *c* and *g* show cells from the lesser brain (cerebellum). They are rather oval in shape, and one or two branching processes come off from the small end of the oval. Those with one process are called **unipolar,** those with two **dipolar.** So characteristic are these forms of cells of special parts of the nervous system, that under the microscope a small piece of spinal marrow could be identified, simply by the presence in it of a multipolar cell, and a small piece of large brain simply by the presence of a pyramidal cell; and so on.

The processes of cells become important parts of nerve-fibres, as will be seen in considering nerve-fibres. Nerve-cells grow, manifest activity, and decay as do other cells.

Nerve-fibres present the appearances shown in fig. 84, *c* and *d*. They are of glassy transparency, and have a double outline as represented in the figure. They thus resemble tubes. The contents of the tube are of a clear jelly-like character. When stained by colouring agents nerve-fibres are found to consist of a rod passing down the centre, called the **axis-cylinder,** which is surrounded on all sides by a white substance, the **white substance of Schwann** or **medullary sheath,** the whole being inclosed in a delicate sheath (**neurilemma**). At intervals gaps occur in the white substance, but the central core is continuous throughout the whole length of the nerve. In *a* and *b*, fig. 84, the gaps in the white substance, which is as if stained black, are shown, and the axis-cylinder is seen crossing the gap. In fibres of the sympathetic system (*e* of fig. 84) no white substance exists, but only the central rod surrounded by the delicate sheath. Thus there is a distinction between **medullated** and **non-medullated** nerve-fibres. A nerve-fibre resembles a wire for conducting electricity, with its central rod of copper and its outer layer of gutta-percha, silk, or cotton, to protect the copper from contact with other conductors. The copper rod is the important part of an

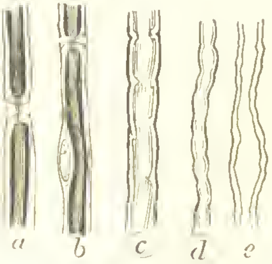


Fig. 84.—Nerve-fibres.

electrical conductor. Similarly the axis cylinder is the important part of a nerve-fibre, and *it is found to be the continuation of a process of a nerve-cell.* Thus nerve-cells and nerve-fibres are related in that the process of one is the axis cylinder and essential part of the other.

Nerve-cells are frequently collected into groups, the various cells of the group communicating with one another. This is called a **nerve-centre.**

Nerve-fibres are associated together in bundles, the bundle being supported and surrounded by connective tissue, and thus a **nerve** is formed.

Ganglia is the term applied to distinct and separate little masses of nerve-cells associated with the fibres related to them.

The **Functions** of nerve cells and fibres are different. The cell is a highly active mass of living material; and it draws nourishment from the blood, supplied to it in abundance. That nourishment not only keeps the cell living, but is to be considered as raw material which the cell works up so as to derive from it force or energy. The cell is thus a little manufactory, deriving its raw material from the blood, and developing from it nervous energy. The nerve-fibre, again, is the conductor of the nervous activity; it affords the pathway along which the force generated by the cell may be discharged. Of course the nerve-fibre, consisting, as it does, of living nervous substance, is also capable of generating energy, but its special function is to conduct influences to or from the cells.

Nervous Action.—It has been seen that nerve-fibres are in connection with nerve-cells, and that the fibres conduct the energy developed in the cell; and so the question arises, "Whither is the energy conducted, to what place does it proceed?" Well, in highly developed creatures like the higher animals and man, nerves proceed to nearly every tissue and organ of the body. They go to muscles and enter even into their very fibres: they are found in the coats of blood-vessels; they have recently been shown to be intimately connected with the cells of glands; they ramify through the skin; they are among the chief parts of the structure of the organs of sense. No difference can be observed in the nerves that supply all these different structures, nor is there any reason to suppose that the energy conveyed along a nerve to a muscle is in any way different from the energy conveyed along a nerve to a gland. Yet the results are different. The activity roused in a muscle reveals itself in the contraction of the muscle, in movement; the activity induced in a gland produces increased action of the gland, increased flow of the gland secretion, the fluid prepared by the gland. Thus it is the organ at the end of the nerve—**the terminal organ,** as it is called—and not the nerve-cell or the nerve-fibre, that determines the mode in which the nerve-energy shall display itself. Nerves that proceed to muscles are called **excito-motor,** because the excitation they cause leads to motion; those that go to glands are called **excito-secretory,** because they excite to secretion; those that are found in the walls of blood-vessels are called **vaso-motor,** because they excite changes in the calibre of the vessels, make them wide or narrow, by causing the muscular tissue in their walls to contract or become relaxed; and there are others that are called **sensory,** for a reason that will be explained immediately. These names, as we have seen, are founded on a mistake, because it is not the fibre that determines motion, or secretion, or sensation, but the organ in which it ends, the terminal organ.

Another question arises, namely, When or why does nervous activity display itself; what causes a nerve-cell or a group of them to discharge its energy along a nerve, so that movement or some other effect is produced? The cause is called a **stimulus,** or an **excitation.** For example, a barrel of gunpowder is a store of energy, but the energy is quiet, latent, confined, and cannot reveal itself until it has been liberated. Apply a lighted match to the barrel: the match excites the powder, causing it at once to liberate and discharge its energy. The lighted match was the stimulus to the gunpowder. So nerve cells and fibres require a stimulus before they will discharge or transmit their energy. Nerve structures may be stimulated in many ways, *mechanically*, by pinching or pricking, or *chemically*, for example something sour taken into the mouth causes at once a great flow of fluid —saliva—into the mouth, because the nerves supplying the salivary glands have been stimulated to increased secretion by the acid substance. Again nervous structures may be stimulated *electrically*. Every one knows that if he takes into his hands the handles of a moderately strong electrical coil, his fingers close over the handles of the instrument, and though he desire it ever so much he cannot let go. That is because the electricity has stimulated the muscles, directly no doubt, but also through their nerves, to contract, and so long as the stimulus remains his muscles remain contracted, thus keeping his hands closed. *Heat* also will stimulate nerves. Now nerve-cells may be stimulated *directly*, that is the stimulus may be applied to them. Usually, however, it is a nerve that is irritated first. The nerve conducts the *impression*, as it is called, which it has received to the nerve-cells; and they, in turn, are stimulated, and discharge their energy along other nerves to muscles, glands, or other structures, as the case may be. There is thus a chain of events following the irritation of the nerve, and to the completed process a term of great importance in nervous physiology is applied, namely **reflex action.**

Fig. 85 will render the meaning of this phrase more easily understood. In the figure, B is a nerve-cell. Leading to it is a nerve A coming from 1 some sensitive surface, say the skin. Connected with the nerve-cell is another nerve C, which passes to a muscle 2. Suppose something (a prick, sting, &c.) irritates the surface 1, immediately an impression is transmitted along the nerve A to the nerve-cell B. The cell receives the impulse, which acts upon it as a stimulus and causes it to discharge its activity along the nerve C to the muscle 2, leading the muscle to contract. This is a simple reflex

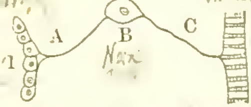


Fig. 85.—Reflex Action.

action, but there may be many much more complicated, in which there may be involved many cells and nerves, and many muscles or blood-vessels or glands, &c. The nerve A leading inwards to the cell is called a *sensory* nerve because it conveys the irritation that has been made on the surface. But sensory is not a good word, because there need be no sensation or feeling result. A better word is, therefore, *afferent* (*ad*, to, and *fero*, I carry), meaning carrying *to* the centre. Similarly the nerve C may be called *efferent* (*e* or *ex*, from, and *fero*, I carry), carrying *from* the centre. Many of the movements and actions of our daily life are nothing more than complicated reflex actions. It is to be noted that such actions may occur without effort of will, and even without our being conscious of them. For example, tickle the sole of the foot of a sleeping man. He withdraws his foot, being at the time sound asleep and totally unconscious. It is a reflex act. The tickling has irritated some nerves of the skin; an impression has been transmitted along nerves upwards to nerve-cells in the spinal marrow. These nerve-cells, being stimulated, have discharged their energy along nerves proceeding to the muscles of the man's leg, the muscles have responded by contracting, and the leg has been moved. All this may have happened without feeling on the man's part, the nerve-centres involved in the action being in the spinal marrow. It is only when the impression reaches the brain by travelling up the spinal marrow that sensation or feeling can arise. Another example of reflex action has already been given—the flow of saliva into the mouth when some acid or sapid substance is tasted.

In warm-blooded animals, such as man, a nervous impression has been calculated to pass along a nerve at the rate of about 200 feet per second.

It has been said that however complicated a nervous structure may appear to be it consists essentially of nerve-cells and nerve-fibres. One can scarcely believe that the complicated brain and spinal cord of man consist only of such apparently simple elements. On tracing the development of a nervous system upwards from the lower to the higher animals, however, one becomes reconciled to the idea.

Fig. 86 shows the nervous system of a crab, consisting of *a* and *b*, little masses—ganglia—of nerve-cells, and fibres radiating from them.

In fig. 87, the nervous system of an ant, there is simply a series of these little ganglia, connected by a double chain of fibres, and fibres radiating from them.

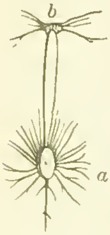


Fig. 86.—Nervous System of a Crab.

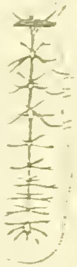


Fig. 87.—Nervous System of an Ant.

It is found that as one advances up the scale of animal life the number of these ganglia increases; they become larger in size and more closely connected together, until a continuous cord is formed, a cord consisting of a combination of cells and fibres, the ganglia at the head at the same time undergoing special development. Thus there is at last reached a stage in the animal kingdom when a continuous spinal cord is found, and masses of cells and fibres exist in the head as a brain, brain and spinal cord forming what is called a **cerebro-spinal system.** The brain is simply a series of ganglia that have undergone special development. In man the brain has reached its highest development, some of the ganglia being greatly enlarged and overlapping others.

Thus the nervous system of vertebrates, or animals having a backbone, consists of the brain, spinal cord, and nerves. The portion termed the brain proper, or **encephalon**, is situated in the cavity of the skull; the spinal cord lies in the canal formed by the rings of the bones called vertebræ existing in the backbone and united by ligaments. The position of these parts is seen in fig. 88.

THE SPINAL CORD.

The spinal cord is lodged in the canal of the spinal column, formed by the rings of the vertebræ. It is from fifteen to eighteen inches long. It extends from the base of the skull, from the foramen magnum of the occipital bone, to the level of the lower part of the first lumbar vertebra, tapering off to a fine thread. It is about the thickness of the little finger, but is thicker in the region of the neck where the nerves for the upper limbs pass off, and also at the lower or lumbar end where the nerves for the lower limbs emerge. It is closely invested by a very delicate connective tissue membrane, the **pia mater,** by which blood-vessels are conveyed to the substance of the cord, having also an outer tough, fibrous coating—the **dura mater.** Between these two are the delicate serous layers of the **arachnoid** membrane enclosing a space between the dura and pia mater. This space contains a certain amount of fluid—the **cerebro-spinal fluid,** similar to the fluid in the ventricles of the brain. The cord is suspended, as it were, and kept in position in the canal by ligaments passing at regular intervals between the inner and outer membranes, the **ligamenta denti-**

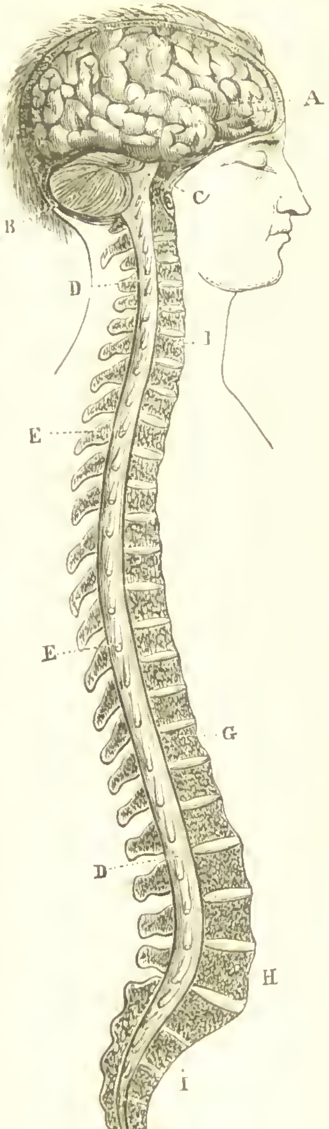


Fig 88.—Position of Brain and Spinal Cord.

A, cerebrum, or brain proper. B, cerebellum. C, pons Varolii, and below it the medulla oblongata. D D, spinal marrow, showing the origin of the spinal nerves. E E, spinous processes of the vertebræ. F, 7th cervical vertebra. G, 12th dorsal vertebra. H, 5th lumbar vertebra. I, sacrum.

culata. Finally, between the cord enclosed by its three membranes and the bony walls of the spinal canal there is a considerable amount of fatty tissue, acting as packing material, imbedded in which are some large blood-vessels. Thus, the cord is supported in the canal by its membranes; and by means of them and of the fluid and packing of fatty tissue it is protected from shocks and jars. Nerves, the **spinal nerves**, pass out from the cord at regular intervals along each side. There are thirty-one of these on each side; and they receive sheaths from the delicate membranes of the cord but pierce the dura mater. They issue from the bony canal by apertures, the intervertebral foramina, left at the sides between the opposing surfaces of the vertebræ, and, having escaped from the backbone, they pass backwards and forwards ramifying in the soft parts of the body. The first pair of nerves comes off between the skull and atlas, the next pair between atlas and axis, and so on down the canal. Thus eight pairs come off in the region of the neck—the **cervical** nerves, twelve pairs are **dorsal**, five are **lumbar**, and five **sacral**, while the last pair comes off behind the **coccyx.** The upper pairs come off at intervals and pass directly outwards through the openings in the canal for them. The lower pairs, however, to which belong the large nerves for the lower limbs, come off very near one another at the lower end of the cord and then pass down the canal in a bundle called the **cauda equina**, from their resemblance to the tail of a horse, one pair passing outwards after another as it reaches its appropriate opening.

In its **Structure** the spinal cord resembles the brain, consisting of gray and white matter, but the arrangement is different. In the brain the white matter is within and the gray matter is spread on the surface of the convolutions. In the spinal cord the gray matter, which is characterized by large cells with many processes represented in fig. 83 (*a* and *e*), is gathered *in the centre* into two half-moon-shaped masses, the backs of the masses being connected at the central part (fig. 89). The white matter, consisting mainly of fibres, is outside of and surrounds these gray crescents. In the centre of the cord, in the midst of the bridge of gray substance that unites the gray crescents, is a microscopically small canal, the central canal of the cord, which is continuous with the fourth ventricle of the medulla oblongata. The cord itself is almost divided into two lateral halves by a fissure or cleft which passes backwards from the middle line in front to within a short distance from the central canal. A division is also made behind between the right and left half of the cord by a partition of the pia mater that dips inwards from the middle line behind, also to a very short distance from the central canal. Thus there is formed a division, as it were, between the right and left side, each side having its own gray crescent, the horns of which point one forwards and the other backwards. The horn pointing forward is called the anterior horn or cornu, the other is the posterior horn or cornu. Now, from these horns there pass off strands of nervous substance which form the roots of the spinal nerves. Thus, from the anterior horn of one side there pass off strands which issue from the cord towards the front, and form the anterior root of a spinal nerve, from the posterior horn of the same side a strand passes off behind to form the posterior root of a spinal nerve. These two strands, having issued from the cord, curve round, meet and join one another at the side, and by their union a spinal nerve of one side is formed, which then passes out of the canal by its intervertebral opening. Similarly from the other side a spinal nerve is formed by the union of an anterior and a posterior root.

Fig. 89 represents the spinal cord cut across, as it would appear on looking down on the cut surface of the section. I is the fissure in front, II is the division between right and left behind, caused by the dipping in of the pia mater. The dotted portion in the centre represents the gray crescents with the connecting bridge, in the middle of which is the central canal *cc*. *ar* is the anterior root, *pr* the posterior root. *g* is a ganglion on the posterior root. The two roots unite to form the spinal nerve *sp*, and the nerve afterwards divides into two divisions, one going to the back of the body, and the other going to the front of the body. The roots of the spinal nerves map the white matter of the cord off into columns. Between the anterior root of each side and the anterior fissure is the anterior column, AC, between the two roots at each side is the lateral column LC; and between the posterior root and posterior fissure is the posterior column PC. In the white matter there are no groups of nerve-cells; but the cells are arranged in groups, NC, in the gray matter, mainly in the anterior cornua (see fig. 89).

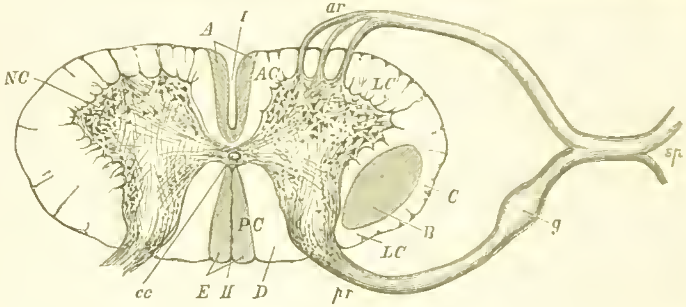


Fig. 89.—Cross Section of the Spinal Cord. Partly diagrammatic. Magnified. For references see text, and for those not described there see p. 272.

Functions of the Spinal Cord.—Suppose that in an animal or man the spinal cord has been crushed or cut through at one point. Take as an example a miner, on whose back a mass of coal has fallen, the man has neither feeling nor power of movement in the parts below the injury. He desires to move his leg, but finds he cannot do it. If his leg is pinched he does not feel it. That is to say the impulse to movement started in his brain by his will does not reach the muscles he wishes to move, because the impulse travelling *down* the spinal cord reaches the seat of injury, and can pass no further because the pathway is destroyed. In the same way the impression produced by the pinch, which, before it can be felt, must travel *up* the spinal cord to the brain, cannot reach the brain because of the injury destroying the path. When the man's foot then is pinched or touched he does not feel it, but his leg may be violently jerked away, to his own surprise, and without him being able to restrain it. What is the explanation of this? The injury has destroyed the continuity of the spinal cord, so that impulses travelling down from the brain to the muscles are stopped, and impulses travelling up to the brain are also arrested. But the whole spinal cord is not destroyed. The impression, produced by the tickling, passes up an afferent nerve to the cord, and though it cannot pass on to the brain to give rise to a sensation, it reaches groups of nerve-cells in the cord below the injury. A change occurs in these cells which results in a discharge of energy down motor nerves to the muscles, which are thus spasmodically moved. That is to say a reflex act has occurred (p. 246). Here then we have indicated two functions of the cord.

I. It acts as a conductor of impressions downwards from the brain, motor impressions, and as a conductor of impressions upwards to the brain, sensory impressions.

II. It acts as a reflex centre. Let us consider these functions a little more in detail.

The Spinal Cord as a Conductor of Impressions.—The various impressions are not conducted indiscriminately in any part of the cord. If the antero-lateral columns of white matter on one side be destroyed, the muscles below the injury on the same side are paralysed, if the whole front half of the cord be cut through, there is complete paralysis of motion of the body below the level of the injury. If, however, the front part of the cord is uninjured, but the posterior portion destroyed, then there is no loss of motion, but loss of feeling below the injury. If the injury is confined to the *posterior portion of one half* of the cord, there is loss of sensation *only on one side of the body*, but on the side opposite to that on which the injury is. The loss of sensation is not complete unless not only the white matter of the back part of the cord, but also the posterior gray matter is destroyed.

The meaning of these facts is just this, impulses passing downward from the brain, that in ordinary course would produce movement, travel along nerve-fibres in the antero-lateral columns, and they are interrupted when that portion is injured; while impressions, travelling up the cord, that would produce a sensation, travel up the posterior part of the cord, and not in the white matter only, but also in the gray, and they are interrupted when the posterior part of the cord is injured. The anterior part of the cord is, therefore, called motor, and the posterior part sensory. Moreover, motor impressions passing down keep to the same side of the cord and pass out by nerves to the same side of the body; but sensory impressions soon after they enter the cord by the nerve of one side cross in the cord to the opposite side, up which they travel to the brain. Thus destruction of one lateral half of the cord causes paralysis of motion on the *same side* as the injury, but loss of sensation on the *opposite side,* because the posterior portion destroyed consists of fibres which have crossed from the opposite side.

The Spinal Cord as a Reflex Centre.—The cells of the gray matter are found all along the cord. They are grouped together, and in certain parts of the cord, notably in the cervical region where the nerves for the arms come off, and in the lumbar region where the nerves for the lower limbs come off, the groups of cells are much more pronounced. The cells of the anterior horns are most abundant, and though cells exist in the posterior horns they are not nearly so numerous. It is undoubted that the cells of the anterior horns are in relation with muscles by means of nerve-fibres, and that they are also in connection with the skin and other sensory surfaces by means of nerve-fibres running in the posterior part of the cord. Thus there is established, without reference to the brain at all, a reflex mechanism. In fact, we might consider the body as made up of so many segments piled up on one another, each segment being presided over by a similar segment of spinal cord, each body segment having sensory nerves conveying impressions to the group of nerve-cells of the spinal segment belonging to it and being supplied with motor nerves, along which impressions from the group of cells could be conveyed. The group of cells in each spinal segment is intimately connected with the cells of segments above and below, and thus an impression reaching the cells of one spinal segment might be so strong as to overrun into the cells of other segments, and thus cause many parts of the body to be affected. Take an example. A child has been allowed to eat improper food, which severely irritates its bowels. Sensory nerves of the bowels are irritated, and powerful impressions are carried up to a centre in the spinal cord. The impressions overrun into other centres, and spasmodic discharges of nerve-energy are liberated from the centres, which passing to the muscles throw them into contraction, and a fit of convulsions is determined. Moreover, it is in the upper part of the spinal cord that there exist groups of nerve-cells which preside over the functions of animal life. Thus centres exist for maintaining the regular action of the heart and the regular movements of breathing; a centre exists there for regulating the size of the pupil, and low down in the cord in the lumbar region are centres for control of the bowel, bladder, &c. Moreover, it would appear that complicated movements, which the child gradually learns to perform by laborious voluntary effort, by direction, that is, from the brain, may, when they become habitual, be carried on by the influence of the spinal cord, a centre in the cord having become trained, so to speak, for the purpose.

Functions of Spinal Nerves.—If destruction of an anterior root of a spinal nerve occur, paralysis of motion in the parts supplied by that nerve results, and the parts supplied are on the same side of the body as is the root when it issues from the spinal cord. If destruction of a posterior root occur, sensation is abolished in the parts supplied by the corresponding spinal nerve, also on the same side of the body. The business of the anterior root is, therefore, to transmit outwards to the muscles impulses leading to movement, that of the posterior root is to receive and to transmit inwards to the cord, and so on to the brain, impulses from the skin, &c., leading to sensation.

THE BRAIN.

Very early in the development of a human being the nervous system is represented only by the spinal marrow in the form of a tube running down the back portion of the body. Running through the whole length of the tube is a central fine canal containing fluid. The first rudiment of brain appears in the form of a small bladder developing from the end of this canal. As it enlarges the bladder becomes constricted in two places, and thus divided into three bladder-like growths. They are called the three **primary vesicles.** As development goes on, by a further process of constriction, dividing the first and third each into two, other two bladders or vesicles are formed, all in line, in communication with one another, and in a row from the front end of the **spinal canal.** In this way the brain develops in all animals with a backbone from fishes up to man. Some of these stages are shown in the accompanying woodcut, taken from Haeckel on *The Evolution of Man.* These five bladders thus formed are called, from the front backwards, the fore-brain, twixt-brain, mid-brain, hind-brain, and after-brain, and they have not appeared till the fourth week of human development. They arise from the three primary vesicles as shown in the following list:—

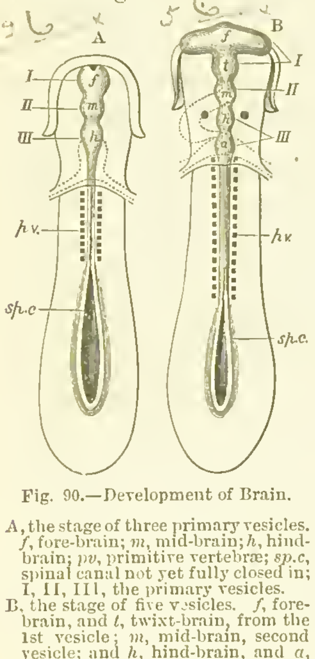


Fig. 90.—Development of Brain.

A, the stage of three primary vesicles. *f*, fore-brain; *m*, mid-brain; *h*, hind-brain; *pv*, primitive vertebræ; *sp.c*, spinal canal not yet fully closed in; I, II, III, the primary vesicles.
B, the stage of five vesicles. *f*, fore-brain, and *t*, twixt-brain, from the 1st vesicle; *m*, mid-brain, second vesicle; and *h*, hind-brain, and *a*, after-brain, from third. Other references as in A.

I.	1. Fore-brain. 2. Twixt-brain.
II.	...3. Mid-brain.
III.	4. Hind-brain. 5. After-brain.

From these elementary structures the whole of the complicated brain is developed by expansion of parts, and by growth of new material and thickenings in their walls. Thus the front portion of the first primary vesicle extends forwards and upwards, becoming double at an early period, and ultimately becomes the cerebral hemispheres, consisting of a right and left hemisphere, mapped off from one another by a longitudinal fissure (see fig. 93) but yet connected at the bottom of the fissure by a broad band, the **corpus callosum.** As they grow they not only extend forwards and upwards, but also backwards and down the sides till they overlap and cover in the parts behind, developed from the other vesicles. This is roughly illustrated by the diagram (fig. 91) from the side. In the lower and side parts of these developing hemispheres are formed two masses of nervous substance, which in the fully developed brain are situated in its base, and are large most important structures or ganglia hid by the hemispheres above them. They consist mainly of grey nerve substance, and appear streaked or striated on the surface. Hence they are called the striated bodies, **corpora striata.** There are other masses of nerve substance developed in the base of the brain, as we shall see, and they are all classed together as **basal ganglia,** of which the corpora striata are the furthest forward. In the second division of the first vesicle a great formation of nerve substance occurs on the floor and side walls, which forms others of the basal ganglia, the **optic thalami,** one on each side of the middle line.

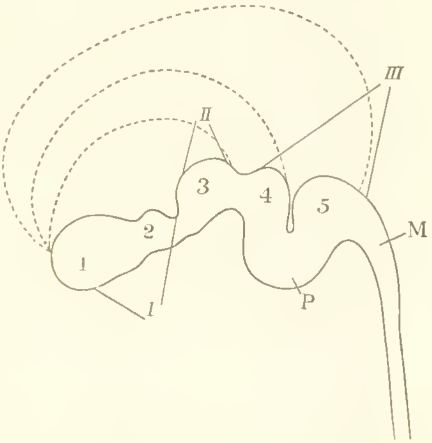


Fig. 91.—Stages in the Development of Cerebral Hemispheres from Fore-brain.

1, 2, 3, 4, 5 refer to the brain vesicles. I, II, III are the parts forming the three primary vesicles. P, pons Varolii. M, medulla oblongata.

The second primary vesicle remains single. In its roof is developed, by new growth, another set of the basal ganglia, the **corpora quadrigemina,** originally one mass, one each side of the middle line, and therefore only double. In this condition it remains in some of the lower animals up to birds, forming the **corpora bigemina.** But, in man and quadrupeds, in the body of each side a transverse groove appears giving the appearance of a fourfold body, hence the epithet quadrigemina. In the base of this vesicle are developed fibrous masses, the **cerebral peduncles** or **crura**, which by passing forwards and backwards connect the cerebral hemispheres and upper part of the spinal cord.

The first part of the third primary vesicle develops into the cerebellum or lesser brain, appearing first as a simple flap of nervous matter in the forepart of the vesicle. In advanced stages it consists of two large lateral lobes connected below by a transverse bridge. the bridge of Varolius, or **pons Varolii.** The after-part of this vesicle becomes the **medulla oblongata**, which forms the upper part of the spinal cord, the connecting mass between spinal cord and brain. We may now add to the list of the primary vesicles, the more important parts developed from them.

I.	1. Fore-brain.	Cerebral Hemispheres, Corpus Callosum, Corpora Striata.
	2. Inter-brain.	Optic Thalami.
II.	3. Mid-brain.	Corpora Quadrigemina and Crura Cerebri.
III.	4. Hind-brain.	Cerebellum and Pons Varolii.
	5. After-brain.	Medulla Oblongata.

It should be added that in connection with the fore-brain there arises a band of nervous matter—the **fornix**, connecting the front and back parts of the cerebral hemispheres, as the corpus callosum connects them transversely.

In connection with the inter-brain are two curious bodies, the **pituitary body**, connected with a prolongation downwards (the **infundibulum**) of the floor of the vesicle, and the **pineal gland**. developed in the back part of the roof of the same portion of the primary vesicle.

The ventricles or cavities in the brain will be understood from this brief sketch. We have seen that the primitive spinal marrow had a fine canal in its centre, and when the brain vesicles were developed the canal, of course, communicated forwards with them. With expansion of some parts of the vesicles and contraction of others by increase in growth, the continuation of the spinal canal becomes transformed into cavities connected by narrow channels. The cavity of the first primary vesicle becomes the **third ventricle**. running between the optic thalami. But as the cerebral hemispheres are developed from the front part of this vesicle one on each side. the third ventricle is prolonged on each side into a **lateral ventricle**. which is a cavity in the interior of the cerebral hemisphere of each side. The lateral ventricle of each hemisphere is thus just a much-expanded side-wing of the third ventricle, and the junction of the narrow third ventricle with the two side-wings forms a Y-shaped passage, the **foramen of Munro.** The cavity of the first primary vesicle communicates behind with the cavity of the middle vesicle, and the cavity of the middle one with that of the posterior primary vesicle. This latter becomes flattened and widened, forming the **fourth ventricle**, the roof of which is covered in by the overarching cerebellum. The cavity of the second vesicle, however, simply remains as a very narrow channel between that of the first (third ventricle) and that of the hindmost vesicle (fourth ventricle). It is encroached upon by growth of nerve substance, instead of being expanded, and forms the **aqueduct of Sylvius.** Thus the central canal of the spinal cord passes up into the fourth ventricle, thence through the aqueduct of Sylvius (beneath the corpora quadrigemina) into the third ventricle between the optic thalami, and the canal then passes forwards and to the right or left through one limb or other of the foramen of Munro into right or left lateral ventricle, into the interior, so to speak, of right or left cerebral hemisphere. It remains to be added that as the right and left hemispheres develop forwards they come to meet one another in the middle line and enclose a very small cavity, that of the **fifth ventricle.** It has, however, as its mode of formation would lead one to suppose, no communication with any of the others. The ventricles always contain a small amount of fluid. In the disease called water-in-the-head the fluid accumulates to a great extent and the ventricles become dilated in consequence. These facts are illustrated in fig. 92.

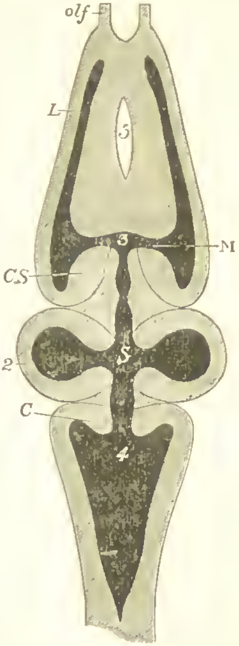


Fig. 92.—Diagram of Brain of Frog opened up to show Ventricles.

4, fourth ventricle; S, aqueduct of Sylvius between 4 and 3, third ventricle; M, foramen of Munro; L, lateral ventricle of left side. C.S, corpus striatum of left side; C, cerebellum; 5, fifth ventricle; 2, corpora bigemina; *olf*, olfactory lobes.

Some brief details will now be given regarding the different parts of the brain.

The brain proper consists of the **cerebrum,** or larger brain, which occupies the whole of the upper and front parts of the cavity of the skull (see fig. 88), the **cerebellum,** or lesser brain, lying beneath the hinder part of the cerebrum, and the **medulla oblongata,** or oblong marrow, which may be regarded as a continuation of the spinal cord within the cavity of the cranium, and as forming the connection between the brain and cord. Included also in the brain are certain masses of nervous matter, lying towards the floor of the cavity of the skull, covered over and concealed by the larger brain, and called **basal ganglia.**

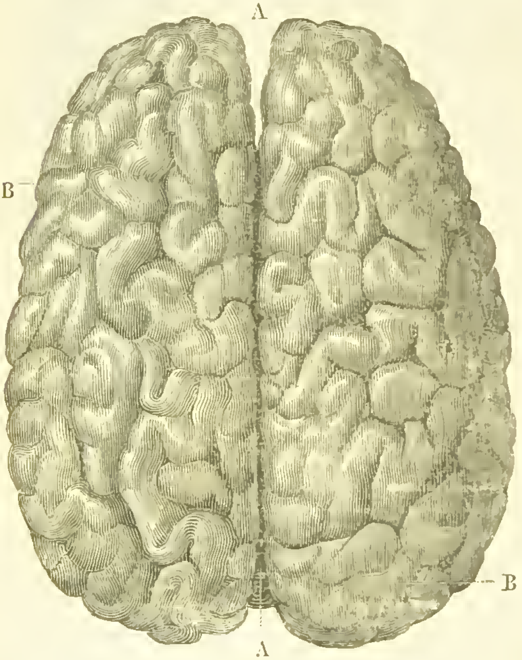


Fig. 93.—View of Upper Surface of the Brain. AA, great longitudinal fissure. BB, cerebral hemispheres.

The cerebrum and cerebellum are almost completely divided into two lateral halves by a deep longitudinal fissure, and their surfaces are divided, by a considerable number of tortuous furrows, nearly an inch deep, into **convolutions.** The gray matter of the brain spread out on its surface is the portion having the highest functions, and its quantity is largely increased by being thus thrown into convolutions.

The **Cerebrum** is oval in form, arched above and somewhat flattened on its inferior surface, which rests on the floor of the skull. Usually its anterior or frontal portion is somewhat narrower than the hinder portion, and its greatest breadth is between the ears. The great fissure, running from before backwards, divides it into the **hemi-**

spheres, but these are connected by a large band of nervous matter, seen in fig. 94, B, called the **corpus callosum.** Dipping into this fissure is a process of the outer membrane of the brain—the dura mater, and to the process the name **falx cerebri** has been given. Each hemisphere is divided by anatomists into anterior, middle, and posterior lobes, corresponding generally to the same regions of the skull. The general appearance of the surface of the cerebrum is seen in fig. 93.

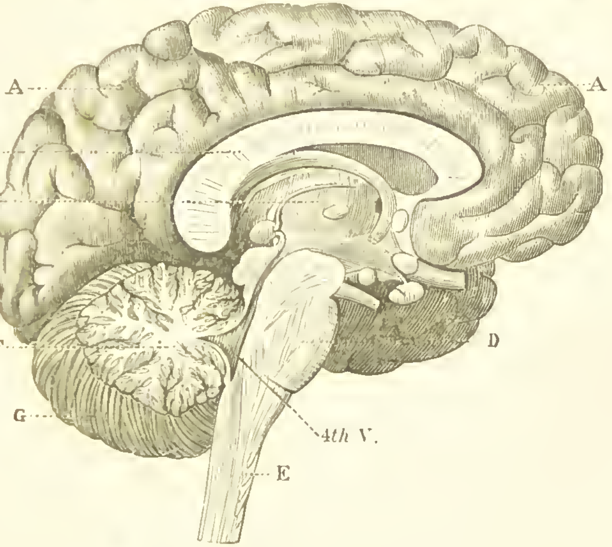


Fig. 94.—View of a Section of the Brain in the Median Line. The inner aspect of the left side is seen.

A, plane of the great fissure. B, corpus callosum. C, optic thalamus. D, pons Varolii, under which is seen the medulla oblongata, or cranial portion of the spinal cord. E, spinal cord. F, section of cerebellum, showing its peculiar arborescent appearance, which has given it the name of "tree of life." G, left half of the cerebellum, showing convolutions. *4th* V, fourth ventricle.

The view of the under surface of the brain (fig. 96), which rests on the floor of the skull, shows the origins of the important nerves, called the **cranial nerves,** the **cerebellum,** the **optic commissure** (2–2) or structure connecting the optic nerves, the **pons Varolii** (PV) or bridge of nervous matter connecting together the two hemispheres of the cerebellum, and lastly numerous convolutions.

The Basal Ganglia.—If we divide the brain into two portions by cutting longitudinally through the great longitudinal fissure, and dissecting a short way towards either side, we find that each hemisphere covers over several large masses of nervous matter, which have been called the **ganglia at the base of the brain.** These are from before backwards: (1) two bodies streaked on the surface, and hence called **corpora striata,** or striated bodies; (2) two bodies behind and a little to the outer side of the corpora striata, supposed by the older anatomists to be connected with vision, and hence called the **optic thalami,** or optic masses; and (3) four bodies, two on each side, called **corpora quadrigemina,** or twin-like bodies.

All these parts of the brain are connected with each other by numerous nerve-fibres. The fibres from the spinal cord pass upwards in the medulla oblongata, those from the posterior part going chiefly to the cerebellum, whilst those from the anterior pass chiefly to the cerebrum. In the cerebrum, cerebellum, and ganglia we also find fibres running from one part to another, as from before backwards and transversely, so as to unite all the parts of the brain and form one complete organ.

A lateral view of the brain is seen in fig. 94, which should be studied with the aid of the description.

The **Cerebellum,** or lesser brain, lies in the posterior part of the cranium, and is covered over in man by the posterior lobe of the cerebrum. It is, as it were, slung on the back of the cerebro-spinal axis, and consists of two hemispheres with an intermediate portion, or middle lobe, sometimes called the **vermiform process.** The whole surface of the cerebellum is divided into convolutions by irregularly-shaped furrows passing transversely. The cerebellum is separated from the cerebrum above it by a partition of membrane, part of the *dura mater.* In some animals, such as the cat, this partition is partially bony. It is called the **tentorium cerebelli.**

The Peduncles of the Brain.—The cerebrum, cerebellum, and spinal cord are connected together by thick bands of fibres called **peduncles** or **crura.** Thus, connected with the cerebellum, there are three pairs of peduncles, two joining it to the spinal cord below, two to the cerebrum above, and two passing transversely and forming the pons Varolii.

Minute Structure of the Brain.—When an incision is made into the brain it is seen to be composed of *white* matter internally, and *gray* matter externally. The white matter is more firm and consistent than the gray matter; indeed, the latter is so soft as to be readily washed away from the brain soon after death by a jet of water. The gray matter forms a layer or web over the surface of the cerebrum and cerebellum, and it also exists in masses at various points in the deeper parts, as for example in the corpora striata, optic thalami, corpora quadrigemina, pons, medulla, and cerebellum. The white matter constitutes the greater portion of the internal parts of the brain, and it consists of nerve-fibres bound together by fine connective tissue. The gray matter consists of a very fine variety of connective tissue to which the name *neuroglia* has been given, and in this lie embedded masses of nucleated protoplasm called *nerve-cells*, having branching processes, as already described. The nerve-cells of cerebrum and cerebellum are of a characteristic shape, the former being triangular (fig. 83, *f*), the latter have two processes proceeding towards the surface and one from the base passing inwards (fig. 83, *g*). They thus both differ from those of the spinal cord, which have many processes, and are called multipolar (fig. 83, *a*, &c.).

The Membranes of the Brain.—The brain and cord are protected by three **membranes,** named also the **meninges.** These are: (1) a strong outer fibrous membrane named the **dura mater,** which closely lines the interior of the skull and forms a loose sheath in the spinal canal, (2) an inner thin membrane called the **pia mater,** which is closely adapted to the surface of the brain and spinal cord, and, being crowded with blood vessels, carries to them their blood-supply, and (3) an intermediate membrane, the **arachnoid,** which lies over the pia mater and under the dura mater. The dura mater may be regarded as the protective covering of the brain, and the pia mater as a special membrane on which blood-vessels divide and subdivide, so as to be of very small size before they penetrate the brain; whilst the arachnoid is really a double membrane, one layer being adapted to the dura mater and the other to the pia mater, the space between these occasionally containing a small quantity of fluid. These membranes are sometimes the seat of inflammation.

Blood-vessels of the Brain.—The brain is very richly supplied with blood. The main arteries enter the base of the brain, dividing and subdividing until they become of very small size; whilst the chief veins tend towards the surface of the hemispheres, where they enter into great cavities or **sinuses,** by which the blood is carried off to the great veins of the neck. The special feature of the arrangements for the blood supply of the brain is that only very small vessels ramify in the brain substance. The gray matter contains a much denser network of fine vessels than the white matter.

Weight of the Brain.—The average weight of the human brain is about 49 oz. for the male and 44 oz. for the female. The average male brain is usually about 5 oz. heavier than that of the female. In both sexes the weight of the brain increases rapidly up to the seventh year, then more slowly to between sixteen and twenty. and again more slowly to between thirty-one and forty. at which time it reaches its greatest size and weight. As age advances it diminishes in weight at the rate of about 1 oz. for each period of ten years.

Other things being equal, the size and weight of the brain bear a general relation to the mental power of the individual. The brains of many eminent men have been found to be 8 to 14 oz. above the average weight. but there are notable exceptions. The brains of idiots are always small; indeed, any weight under 30 oz. seems to be invariably associated with idiocy. The human brain is absolutely heavier than that of any other animal except the whale and the elephant. The brain of a whale, 75 feet long, weighed upwards of 5 lbs., whilst that of an elephant is from 8 to 10 lbs. The average proportion of the weight of the brain to the total weight of the body is greater in man than in most other animals, being about 1 to 36·5; but in some small birds, the smaller monkeys, and in some rodents, the weight of the brain to that of the body is even greater than it is in man.

BRAIN FUNCTIONS.

The **cerebral hemispheres** are associated with mental phenomena—feeling, thinking, and willing. The following are the chief facts that support this view:—(1) Inflammation of the membranes (termed *meningitis*) covering the surface of the brain, especially if it involve the superficial layer of *gray* matter, causes delirium, and afterwards profound insensibility or coma; (2) inflammation at the base of the brain, or any irritation of the *white* matter, causes paralysis of motion or convulsions; (3) in some circumstances considerable portions of grey matter may be cut away by accident, or destroyed by an abscess or by a tumour without any marked physiological effects; (4) in some cases sudden depression of a portion of the cranium into a convolution, or a sudden blow on the head, has either arrested the mental faculties as a whole, or has affected the action of one only, as, for example, the memory; (5) diseased conditions of the grey matter, such as congestions, softenings, degenerations of structure, or the formation of new products, are always associated with the various forms of insanity.

All of these facts, along with others gathered from experiment and from comparative anatomy, show that the hemispheres, and more especially the grey matter on their surface, are connected with mental states. In a sense the cerebrum is the organ of the mind, and consequently all forms of insanity are simply the result of disease or perverted action of this organ.

The **corpora striata** are concerned in the transmission downwards of motor influences, that is, nervous impulses which excite muscular contraction. Injury or disease of the corpus striatum of one side causes paralysis of motion on the opposite side of the body, the motor fibres, as will be explained (p. 271), crossing in great numbers in the medulla. Motor impulses do not originate in the corpora striata, but these organs receive the impression from the higher centres in the cerebrum and transmit it downwards. Again, they may be concerned in reflex movements without consciousness. Thus a nervous impression, starting from the eyes, reaching the corpora quadrigemina, is probably transmitted forwards to the corpora striata, and thence passes downwards to excite muscular contractions.

The **optic thalami** are sensory centres receiving impressions, probably those of touch, and transmitting them upwards to the cerebral hemispheres, where they may arouse consciousness. Injury or disease of these organs on one side causes loss of sensibility, or disordered sensibility, on the *opposite* side of the body, as the majority of sensory fibres cross from one side to the other in the back part of the spinal cord. Just as the corpora quadrigemina are the recipients of *visual* impressions which may result in complex muscular movements, as those of walking without consciousness in somnambulism, so the optic thalami perform the same functions in relation to impressions of touch.

The **corpora quadrigemina** are connected with the sense of vision and with the movements of the pupil. Disease or injury causes dilatation of the pupil and blindness. The corpora also receive visual impressions which may be transmitted upwards to the cerebral hemispheres, resulting in a sensation of light; or they may cause coordinated or regulated movements without sensation. Thus visual impressions may cause well-regulated movements without the person being actually conscious of what he sees, as happens in somnambulism.

The **pons Varolii** contains motor and sensory fibres passing upwards and downwards, and, in addition, it contains centres of gray matter which are connected with the roots of some of the cranial nerves. Irritation of the pons causes very severe convulsive spasms. The pons also contains, as already stated, transverse fibres connecting one-half of the cerebellum with the other half, thus securing co-operation between the two portions, but the exact way in which this is done is unknown.

The **cerebral peduncles**, seen immediately above the pons in fig. 94, contain both sensory and motor fibres. The sensory are in the back part of the peduncles, and pass upwards to the corpora quadrigemina, optic thalami, and posterior lobes of the cerebrum, whilst the motor fibres pass downwards from the corpora striata in the anterior part of the peduncles. Injury to one peduncle sometimes causes an animal to move to the side opposite the injury, so as to describe a circle, somewhat in the manner of a horse in a circus.

The **cerebellum** is the regulator or co-ordinator of muscular movements. The mechanism by which it does so has not yet been satisfactorily explained. It receives nervous impressions of a visual character from the corpora quadrigemina, of a tactile character by nerve-fibres coming from the skin and passing up the back part of the spinal cord, and also impressions associated with the sense of equilibrium by the auditory nerve from the semicircular canals in the ear. (See EAR.) Disease of the cerebellum in the human being is rare, but when it does exist there is usually blindness, a dilated pupil, giddiness, a tendency to move backwards, and a staggering irregular gait. There is no loss of consciousness or other disturbance of the mental functions.

The **maintenance of equilibrium**, and the duly balanced combination of a variety of muscular movements to effect a definite object, seem undoubtedly to depend largely upon the integrity of the cerebellum. Let any one compare the movements of an infant's arm as it stretches out its hand to take something held out to it, the jerky, ill-directed, excessive, and ineffective movements, with those of an older person, quiet, straight, steady, and effective, and he will realize that the difference consists in this, that in the child the contractions of the different muscles are not properly proportioned, and so the arm is jerked, now one way, now another. In the older person experience and practice have taught how properly to control the various muscles. Similarly the maintenance of equilibrium is the result of numerous muscles acting in harmony. But this harmonious action is the result of the education of some part of the nervous system, for the contractions of muscles are regulated by nervous impulses. It is natural to conclude that the due regulation and control of all the muscular movements is the business of some particular nerve ganglia. Experiment and the results of disease point, as already indicated. to the cerebellum as performing this function. If so, the cerebellum must somehow be kept in touch, so to speak, with the muscles of the body. A man standing on the deck of a rolling ship maintains his equilibrium in spite of the unsteadiness of the surface on which he stands. As the ship rolls to one side his body sways to the other, and the swaying of his body must be in proportion to the movement of the ship. In other words, his equilibrium depends not only upon a certain ordered movement of complex groups of muscles, but on a certain position of his body in space, a position related to that of the surface on which he stands. Assuming that it is through the cerebellum that the muscular movements are properly combined, the cerebellum must not only be in touch with the muscles, as we have said, but must also have some information as to the position of the body and limbs in space. Suppose a man on the deck of a rolling ship, talking to some one and so preoccupied. The ship is rolling in a regular sort of fashion and he is keeping his balance, but, unnoticed by him, a wave suddenly strikes the ship, and substitutes another kind of roll. The man is utterly upset, clutches at anything near at hand, and for an instant or two is obviously quite bewildered, till, having steadied himself by something, he regains his mental and corporeal balance. Now suppose the person to whom he was talking had said to him, "Look out, there's a big wave," he would have quickly turned, would have seen what was about to happen, and, watching the ship, would have remained undisturbed. That is to say, his sight would have given him information by which new muscular movements would have been adopted to suit the altered roll of the ship. As it was, thrown off his balance, he grasped at some fixed object and so *steadied himself with his hands.* That is to say, by *touch* he obtained the information his *eyes* could have supplied him with. To make this latter point clearer, suppose the same man comes up on deck at night, from the lighted saloon. It seems at first pitch-dark on deck, and he moves along grasping the hand-rail of the deck-house or the rail on the ship's side. If he wishes to cross by a way where there is no rail to guide him, holding the rail he is about to leave he peers through the darkness till he catches a glimpse of something he may grasp on the other side of the deck, and, waiting a favourable moment, darts across. Perchance at that instant the ship gives a lurch, and deprived of the guidance both of sight and touch, down he goes on the deck. In short, to apply the two illustrations given, the cerebellum is guided in its business of regulating and co-ordinating muscular movements by impressions received through sight or touch. If one is coming down a stair in the dark one runs the hand along the hand-rail, or keeps touching the wall with the finger, *to obtain impressions of touch wherewith the cerebellum may be guided in its business.* If the person thinks he has reached the bottom of the stair, when really one step yet remains, we all know how the failure of the foot to feel the ground as is expected completely upsets his balance and may serve to send him headlong. The guiding sensation in this case was received by contact of the foot with the ground. The cerebellum, then, in co-ordinating movement is dependent upon certain guiding sensations, some of which are supplied by the sense of touch, the impressions travelling up the spinal cord in the posterior portion, and it may be passing through the optic thalami before reaching the cerebellum, some of which are visual impressions received by the eye and transmitted through the corpora quadrigemina.

It is to be added that other guiding sensations, indicating particularly the position of the body in space, are transmitted from the semicircular canals of the ear (see p. 351). These canals, though intimately associated with the organ of hearing, seem to have little to do with the function of hearing, since their destruction is not attended by deafness. On the other hand their destruction in animals is attended by disorderly movements whenever voluntary motion is attempted, and in the human subject disease of the semicircular canals is attended by giddiness. A good deal of evidence of a nature akin to that just indicated exists, leading to the conclusion that the semicircular canals play an important part in supplying the guiding sensations through which equilibrium is maintained, and movements of various muscles and groups of muscles properly co-ordinated for the achievement of definite purposes. The three semicircular canals of each ear are disposed in three different planes, one canal of each ear being in the same plane. Each canal contains fluid, and projecting into the fluid are cilia connected with cells which are in communication with nerve filaments. With different movements of the head, the pressure of the fluid on different parts of the same tube and in different tubes will undergo variations; which will affect the nerve filaments through the cilia. Thus impressions are produced which are believed to give rise to a notion as to the position of the head in space, on which equilibrium to some extent depends.

The **medulla oblongata** is the upper inch and a quarter of the spinal cord which becomes continuous with the brain. It consists, like the spinal cord, of columns of white fibres and masses of gray matter, but differently arranged. The gray matter loses the arrangement it has in the spinal cord and is broken up into masses which form centres of origin for various nerves. The anterior fissure of the spinal cord continues upwards in front of the medulla till it is lost in the upper part. Towards the upper portion of the posterior part of the medulla the posterior fissure opens out and expands into the floor of the fourth ventricle.

A remarkable arrangement of the white matter occurs. On each side of the anterior fissure is a bundle of white substance, which is found to consist of fibres of the anterior column and also of the lateral column of the cord. These are called the **anterior pyramids** of the medulla. If the fibres are traced downwards it is found that the part of the pyramid, say of the right side, which belongs to the anterior column is continuous with the anterior column of the same side of the cord, while the part belonging to the lateral column crosses over to the opposite side of the cord as soon as it reaches the lower part of the medulla. At the lower part of the medulla, that is to say, bundles of fibres cross one another, one bundle of the right pyramid crossing over and running down in the lateral column of the left side of the cord, one bundle of the left pyramid crossing to become part of the lateral column of the right half of the cord. This is called the **decussation of the pyramids.** If the fibres are traced upwards those of the right pyramid are found to be connected with the right half of the cerebral hemisphere through the right corpus striatum, while those of the left pyramid are connected with the left side of the brain. Thus fibres *from the right cerebral hemisphere*, after passing through the right corpus striatum and peduncle, pass on in the right anterior pyramid of the medulla, but at the lower part of the medulla cross over to the *left side* of the cord and are distributed to the left side of the body, while fibres from the *left* cerebral hemisphere cross over in the medulla to the *right* side of the body. It is in the direction thus indicated that impressions due to the action of the will pass downwards to lead to movements. Thus if some interruption occurs in the right side of the brain or right corpus striatum it is the left side of the body that is cut off from communication and so paralysed, while a similar disorder of the *left* side of the brain causes paralysis of the *right* side of the body. On the outer side of the anterior pyramids are two oval masses, one on each side, called the **olivary bodies.** They contain a mass of nerve-cells in their interior whose business has not been discovered. Round from these bodies and nearer the back of the medulla are two rounded columns, the **restiform bodies,** which are continuations upwards of part of the posterior columns of the cord. They pass on to the cerebellum. On the back of the medulla, one on each side of the posterior fissure, are two small columns, the **posterior pyramids,** which are continuous with a small part of the posterior columns of the cord next the posterior fissure, the fibres of which pass on to the cerebral hemispheres.

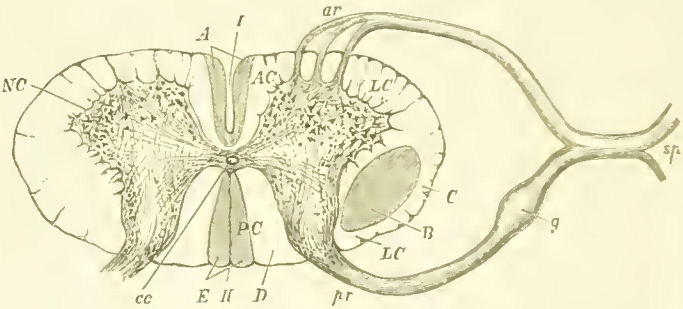


Fig. 95.—Cross Section of the Spinal Cord. Partly diagrammatic. Magnified.

A, part of the anterior column of cord passing through anterior pyramid to cerebral hemisphere of *same side*. B, part of lateral column crossing at decussation of pyramids in medulla to *opposite side*. C, part of lateral column, and D, part of posterior column going on to cerebellum. E, remainder of posterior column that passes to cerebral hemisphere.

It will thus be observed that the cord is continuous with various parts of the brain through the medulla oblongata. Part of the anterior column of one side of the spinal cord is connected with the cerebrum of the same side, part of the lateral column of one side is connected with the cerebrum of the opposite side. Part of the posterior column of the cord is in communication with the cerebellum, part with the cerebrum. The diagram indicates these parts of the spinal cord and their relation to the brain.

Functions of the Medulla.—The medulla is regarded as a great nervous tract for transmitting sensory and motor impressions, and also as the seat of a number of centres for reflex actions of the highest importance to life. Motor transmission, that is, the transmission of nervous influences from above that result in contractions of muscles in some part of the body, occurs chiefly at the anterior part of the medulla. Here, as already mentioned, the motor fibres *cross from one side to the other, so that the right half of the brain is connected with the left side of the body*, and *vice versâ*. Through the medulla sensory impressions also pass, that is, impressions from below upwards, from the surface of the body to the brain, resulting in sensation or feeling; but their route is not accurately known, though they must pass through the restiform bodies and posterior pyramids.

The medulla is remarkable as being the seat of a number of reflex centres connected with the movements of the heart, the movements of respiration, the influence of the nervous system on the blood-vessels, the movements of swallowing, and the secretion of saliva. In addition, it is at least partly the origin of many of the important cranial nerves. Consequently, injury to this part of the nervous system is quickly fatal, and in nervous diseases, or towards the close of life, when the power of swallowing is lost, we may infer that the medulla has become affected.

Summary of Brain Functions.—Thus, to sum up the functions of the brain, the cerebral hemispheres are believed to possess the highest nerve centres, those centres, namely, whose activity is associated with intelligence, thinking, willing, feeling, and consciousness generally. Under these, however, is a series of subordinate or lower centres, first of all those of the ganglia at the base of the brain, next those of the cerebellum, then those of the medulla, and lastly those of the spinal cord. Of the basal ganglia the corpora striata possess centres for voluntary motion, the optic thalami centres for sensation, and the corpora quadrigemina also for sensation, especially connected with vision. The centres in the cerebellum are for regulating muscular movements; and in the medulla are the chief centres that maintain the movements of heart, breathing, &c., necessary for life. These centres are connected together by strands of nerve-fibres, peduncles, &c. One or two illustrations may make these facts more easily intelligible. Suppose a man wills to move his right arm, corresponding to the act of will some change takes place in the higher centres in the left cerebral hemisphere, a message is transmitted from these along nerve-fibres to the lower centres for motion in the left corpus striatum, and from these the message is further transmitted through the medulla, in which it crosses to the opposite side and thence down the right side of the spinal cord and out by the spinal nerves to muscles of the arm, which are thereby stimulated to contraction, and the arm is moved.

Again, suppose a man's hand is hurt with a pin, the impression is transmitted by nerves to the spinal cord. In the spinal cord the impression may be received by a centre, and changes may occur which result in an impression being by reflex action sent outwards by nerves to muscles, leading to the withdrawal of the hand from the agent that hurts it. This may happen, as already explained (Reflex Action, p. 246), though the man is asleep. But the impulse may further be transmitted up the posterior part of the cord and reach the higher centres in the cerebrum, when the person becomes conscious of pain.

Take a final illustration. A man is walking along the street, and sees an obstacle in his path. The impression of this obstacle received by the eye is sent on to the corpora quadrigemina, whose centres receive it and send it upwards to the higher centres in the cerebrum, when the man becomes conscious of seeing. He decides to walk round the obstacle, and thereupon impulses are transmitted down to the corpora striata, and so to the spinal cord, and down to muscles of the leg, causing the proper movements to effect the end aimed at. But suppose the man is walking through the street with his mind busily occupied with something, he is unaware of anything in his path, nevertheless he walks round it just as if he were fully aware, just as a sleep-walker will walk round objects in his way when he is asleep. The explanation given is that the impression from the eye reaches the corpora quadrigemina, and on being transmitted to the higher centres finds them occupied; but the impulse is not stopped. It is transmitted also forward to the corpora striata, acting as reflex centres for motion, and from them impulses pass down the spinal cord, which produce the required movements of muscles. This is an example of a very **complex reflex action.**

SPECIAL CENTRES IN THE BRAIN.

Some remarkable experiments made by several continental observers, and, in our own country, specially by Dr. Ferrier of London, seem to show that the brain does not act as a whole in all its various operations, but that certain parts of it have certain duties devolving upon them. The results of these experiments are in harmony with facts known long before, through the agency of disease. Thus it was known by examinations after death, that destruction of certain limited parts of the brain, caused, for instance, by bursting of a blood-vessel, produced effects dependent upon the seat of the disease. But the experiments alluded to seem to show that little areas of the brain are set apart for the performance of certain duties, and that if these little areas are destroyed, as a general rule no other part of the brain can take up the duty, which is consequently neglected. Thus there are areas, or nerve-centres, for the reception of impressions travelling to the brain from the ear, which give rise to the sensation of sound, and if those areas are destroyed the person is deaf. Similarly there are centres for sight, the destruction of which produces blindness. Dr. Ferrier has also been able to mark off certain small parts of the surface of the side of the brain which preside over certain movements of muscles, for example the movements of the leg necessary for climbing, of the arm for swimming, and so on, the destruction of which renders the person unable to perform these movements. So that certain functions of the brain are said to be *localized*. A good example of this is afforded by a disease called **Aphasia**, which so affects a person that he loses the power of speech. This is not due to any paralysis of tongue or other speech organ, but the person can no longer give expression to his ideas in language or in writing; he has lost the power, that is, of associating ideas with their corresponding words or symbols. At the same time, in cases of pure aphasia no other sign of disease may be apparent, and the person may be as intelligent and as readily understand what is spoken by others as before. Now this loss of the faculty of speech is associated with disease in a particular and limited region of one of the convolutions in the front of the brain on the *left* side.

Phrenology.—The view that certain little areas of brain substance are connected with certain functions is not to be confounded with phrenology, which maps out on the outside of the skull certain regions said to be devoted to certain emotions, &c., the prominence of the regions indicating the amount of development of the faculty, emotion, &c. The brain exhibits no such divisions as phrenology creates, still less can any prominence or depression on the outside of the head indicate, through scalp and bones, the shape of that part of the brain within. The phrenological theory was first propounded by Gall and Spurzheim in the beginning of the present century.

THE CRANIAL OR CEREBRAL NERVES.

There is a set of nerves, called the cranial or cerebral nerves, which pass from the brain through different openings in the skull, and are distributed over the head and face as well as to some parts of the trunk and certain of the internal organs. The nerves come off in pairs, one from corresponding parts of each side of the brain. Fig. 96, which represents the base of the brain, shows the places where these nerves issue from the brain substance. Reference should be made to that figure and to the description which accompanies it.

1. The nerves of the first pair are the **olfactory.** They are bundles of very delicate nerve filaments which come off from the olfactory bulbs which lie under the anterior lobe of the cerebrum. They pass down into the nasal cavity through the ethmoid bone. They are nerves of the special sense of **smell.** (See SMELL.)

2. The nerves of the second pair are devoted to the sense of **sight.** They are the **optic** nerves and pass forwards into the cavity of the orbits to reach the eyeballs. (See p. 313.)

3. The nerves of the third pair are **motor,** also passing

into the orbits to supply the muscles of the eyeball. They are the nerves of motion for the muscles that turn the eye upwards, downwards, and inwards, and for the muscle that lifts the upper eyelid. They also supply the iris, that is, the circular curtain of the eye, by whose contractions the pupil of the eye is made larger or smaller. They leave unsupplied the muscle that turns the eye outwards, and another that turns it downwards and outwards. Suppose this third nerve to be paralysed, the eye could not be turned directly upwards, or downwards, or inwards, but would be wholly under the influence of the two muscles already mentioned as independent of the third nerve. The eye would thus, by these two muscles, be kept drawn downwards and outwards. The upper eyelid would also be

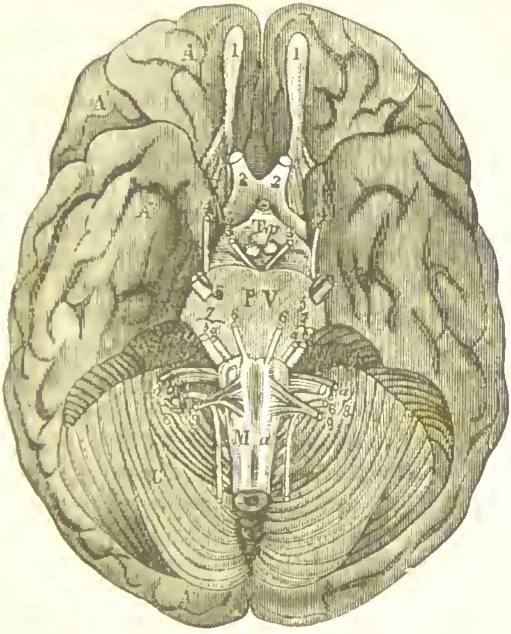


Fig. 96.—View of the Lower Surface of the Brain.

A, anterior lobe. A′, fissure of Sylvius. A″, middle lobe. A‴, posterior lobe. C, cerebellum or lesser brain. Ma, medulla oblongata. PV, pons Varolii. Tp, the pituitary gland. 1-1, first pair of nerves, or *olfactory* nerves. 2-2, second pair, or *optic* nerves. 3-3, third pair, or *common motor nerves* to *muscles of eyeball*. 4-4, fourth pair, or *pathetic nerves* for one muscle of eyeball. 5-5, fifth pair, *trifacial* or *trigeminal*, giving sensibility to face, tongue, and teeth, and motion to muscles of mastication. 6-6, sixth pair, or *abducent* nerves, to external rectus muscle of eyeball. 7-7, seventh pair, consisting of two portions—*a*, *facial*, giving power of motion to muscles of face, and *b*, *auditory*, or nerve of hearing. 8-8, eighth pair consisting of three portions—*a*, *glosso-pharyngeal*, supplying sensibility to tongue and back of throat, also partially motor; *b*, *pneumogastric*, supplying throat, heart, lungs, and stomach; and *c*, *spinal accessory*, giving motor power to certain muscles of neck. 9-9, ninth pair, or *hypoglossal*, supplying power of motion to tongue and to several muscles in neck.

paralysed, and would droop over the eyeball, while the pupil would be very large and immobile. It is obvious, therefore, that one eye would squint very much, and there would be double vision, two objects would be seen for one, owing to the want of united action between the two eyes.

4. The nerves of the fourth pair are the **pathetic** pair, because the nerves supply that one of the muscles, omitted by the third pair, whose contraction aids in giving the downward turn to the eyes.

5. Each one of this pair of nerves is in three divisions, and proceeds mainly to the face. It is, therefore, called **trifacial.** They are mixed nerves, partly sensory and partly motor. The first division, however, is purely sensory, and passes into the eyeball, on which it confers sensibility. The second division is also purely sensory, and gives sensation to the nose, and gums, and cheeks. The third division is partly sensory and partly motor. Its sensory branches confer sensibility for taste on the anterior two-thirds of the tongue, and ordinary sensation on the inner side of the cheeks, on the teeth, and also on the scalp in front of the ear. Its motor branches supply the muscles of mastication. Thus, paralysis of the fifth pair of nerves would destroy the sensibility of the eyeball, and would, moreover, cause ulceration and inflammation to appear in it, would destroy to some extent the sense of smell and the sense of taste, would abolish sensation from the skin of the face, and would cause paralysis of the muscles of mastication, so that the movements of chewing could not be performed. If paralysis occurred to the nerve of one side only, that side of the face and tongue would be deprived of feeling, and the muscles of that side of the jaw being palsied the jaw would be wholly under the control of the opposite side, and would be pulled to the other side, so that the upper and lower teeth would not correspond.

6. The sixth pair is called the **abducent** or abducting pair of nerves, because they are **motor** nerves and supply the muscle that abducts or turns the eye outwards. This muscle was omitted by the third pair. Paralysis of the

nerve leaves the eyeball under the influence of the opposite muscle, namely, that which turns it inward, so that the eye has an inward squint.

7. In each of the seventh pair of nerves there are two portions: the one called **portio mollis** (soft portion) is sensory, and is the **auditory** nerve—the nerve of hearing (see EAR); the other, called **portio dura** (hard portion) or **facial** nerve, is motor, and supplies the muscles of expression. Thus paralysis of the auditory portion would cause deafness; paralysis of the facial would produce palsy of the muscles of the face. The result of facial palsy is that the affected side is smooth, unwrinkled, and motionless; the eyelids, being also palsied, are widely open and cannot be closed; and the face is wholly under the control of the muscles of the opposite side, which, having it all their own way, drag towards that side, so that the mouth is pulled to the sound side.

8. The eighth pair is very complex. The eighth nerve of each side consists of three trunks which arise from the medulla oblongata, and leave the brain by one opening.

The first trunk is called **glosso-pharyngeal** (*glossa*, the tongue, and *pharynx*, the throat) because it supplies the throat and back part of the tongue. It is partly sensory, conferring taste on the back part of the tongue, and partly motor.

The second trunk is the **pneumogastric** (Greek *pneumōn*, the lung, and *gaster*, the belly) or **vagus** nerve. It is both sensory and motor. Passing from the medulla it descends on the gullet to the stomach, sending off, on its way, branches to the throat, the box of the windpipe, lungs, and heart. Paralysis of one of its branches causes loss of voice; some of its branches exercise a restraining influence on the movements of the heart, others convey impressions to the brain, which result in quickening or slowing movements of breathing; while by means of the branches passing to the stomach impressions are conveyed upwards to the brain which inform us of the condition of the stomach, and are the means by which we experience feelings of hunger, nausea, pain in the stomach, and many other indefinite sensations which we associate with that organ.

The third trunk of the eighth pair is the **spinal accessory.** It is a motor nerve, part of it, the accessory part, joining the pneumogastric, and part proceeding to two muscles, one of the neck, the sterno-mastoid, and the other of the back, the trapezius (see Plate).

9. The ninth pair of nerves is the **hypoglossal** (*hupo*, under, and *glossa*, the tongue). It is a motor nerve, and passes along the under surface of the tongue to its tip. Paralysis of the nerve of one side renders that side of the tongue flaccid, and on putting the tongue out of the mouth it will be pushed out with its tip towards the affected side. Paralysis would also cause difficulty of speech, and difficulty of swallowing owing to the tongue not being able to perform the first act of swallowing, namely, pushing the food to the back part of the mouth.

THE SYMPATHETIC SYSTEM OF NERVES.

At each side of the vertebral column, from the base of the cranium to the coccyx, there is a chain of swellings. These are the ganglia of the sympathetic system, and there are twenty-four or twenty-five of them on each side. The ganglia of one side are connected together by fibres running between them, while fibres also pass from the chain of nerves to the spinal nerves in the neighbourhood. At the coccyx the two chains unite in a single ganglion. At the upper end the chain of each side passes up into the cranium and becomes intimately connected with the cranial nerves. In the neck branches pass from the chains of ganglia to the lungs and heart. From the ganglia in the chest three nerves pass off, called the **splanchnic** nerves, which together form a complicated net-work or plexus of nerve-fibres in the upper part of the abdomen. From this sympathetic plexus branches pass along blood-vessels to the stomach, liver, intestines, kidney, and other abdominal organs. A similar net-work of sympathetic fibres is situated lower down in the pelvis, from which branches pass to the pelvic organs. Thus in general the sympathetic system of nerves, while found intimately connected with the cerebro-spinal system, is found specially accompanying blood-vessels and supplying the glands and viscera, that is, the hollow organs of the body.

The **Functions of the Sympathetic** nerves are specially connected with the processes of organic life, the movements of the heart and of respiration, the work of the stomach and bowels in digestion, the process of secretion in glands, and so on. The impulses that proceed along the sympathetic nerves are not subject to voluntary control, and thus all those actions that have been mentioned that are necessary to the life of the body and the harmony that evidently subsists between the internal organs, which unites their action to one end—the maintenance of the animal life, are affected by the sympathetic system. One special function of this system is the control of the blood-vessels. By means of nerves distributed to the muscular coats of the arteries the calibre of these vessels can be varied, so that at one moment they will permit a large quantity of blood to pass to a part, and at another moment will contract so as to diminish the supply. This also is beyond the control of the will, and is effected by the sympathetic through a reflex arrangement, the centre for which is in the medulla oblongata. This has been explained in more detail in the chapter on the circulation of the blood.

THE DISTRIBUTION OF NERVES.

The distribution of the cranial nerves has been already indicated. Each spinal nerve, after it has issued from its opening in the vertebral column, splits into two divisions, one of which proceeds to supply parts behind the spine, while the other passes forward towards the front. The first eight spinal nerves on each side are called *cervical*, the next twelve are *dorsal*, the next five *lumbar*, then five *sacral*, and one *coccygeal*. The anterior divisions of the first four cervical unite to form what is called the **cervical plexus**, from which branches are supplied to the muscles of the neck. One very important nerve springing from the group is called the **phrenic**, which passes down the front of the chest to supply the diaphragm or midriff, upon the movements of which breathing so much depends. The other four of the cervical nerves and one of the dorsal unite to form the **brachial plexus**, from which nerves proceed to the upper limb. They enter the arm from the arm-pit, which they cross in company with the large blood-vessels for the limb. One of them winds round a groove in the upper arm-bone and passes to the muscles of the back of the arm. It is called the **musculo-spiral** nerve. A second, the **ulnar** nerve, descends on the inner side of the arm. At the elbow it rests in an interval between the inner projecting process of the humerus and the point of the elbow. When the elbow is knocked at this place the shock given to the nerve produces the sensation ascribed to "knocking the funny bone." The nerve passes to supply the little finger and the neighbouring side of the ring-finger. If these two fingers become numb, therefore, it is due to paralysis of this nerve. The remaining fingers and the thumb side of the ring-finger are supplied by the **median** nerve, which passes down the middle of the arm. All these nerves are *mixed*, that is, they confer power of motion and sensation.

Of the twelve **dorsal** nerves the posterior divisions supply the muscles and skin of the back, the anterior divisions supply branches, called **intercostal nerves**, to the spaces between the ribs.

The five **lumbar** nerves also send their posterior branches to the back; while the anterior divisions of the first four unite to form a group called the **lumbar** plexus. From it branches pass to the abdomen and genitals, and large branches to the muscles of the front of the thigh, and to the skin of the front and inner side of the thigh, and to the skin of the inner side of the leg and foot.

There is also a **sacral** plexus, formed by the anterior divisions of the sacral nerves, reinforced by the last lumbar.

From this plexus proceeds the largest nerve in the body, the **sciatic** nerve—a neuralgic affection of which is called sciatica. It gives branches to the muscles at the back of the thigh, and branches also to muscles below the knee, and to the skin of the leg and foot. The nerve escapes from the pelvis just outside of the seat bone, and passes right down the middle of the back of the thigh till the back of the knee-joint is reached, where it divides into two branches, called **internal** and **external popliteal**. The first of these branches continues the main course down the back of the leg, where it is called **posterior tibial**. It divides on the inner side of the heel into two branches, which between them supply the sole of the foot and the sides of the toes. The external branch turns round below the knee to the front of the outer side of the leg, down which it passes as the **anterior tibial**, supplying muscles on the way, and ends in branches to the skin of the back of the foot.

SLEEP.

One of the characteristics of all living things is their *periodicity*. Thus plants have their period of activity, culminating in the production of flower and fruit, and their period of inactivity during which they appear quite without life and sap. Not only have they their annual periods of activity and inactivity, but also daily periods, their alternations being so largely dependent upon light and heat. Thus while ordinary flowers flourish mainly during the daytime, the night-flowering cactus blooms and emits its perfume during the night. Animals also exhibit this periodic character. Most notable examples are the hybernating animals, which with the access of winter's cold are subject to a remarkable diminution of their bodily processes, so that they pass the winter in a condition of unconsciousness, waste being reduced to a minimum, and the bodily function being just performed sufficiently to maintain the spark of life, which the return of heat reanimates into a flame. Human beings also present many instances of a periodic character. The chief is undoubtedly exhibited by the heart. This organ might seem at first to be perpetually active during the whole of a person's lifetime; but it is not so. The movement of the heart is rhythmic, the rhythm consisting in regularly alternating periods of work and of rest. Thus, at the close of each contraction of the heart, signified by the beat against the chest wall, there is a pause, and the period of contraction is in the proportion of $\frac{3}{5}$ths to that of the rest, which is $\frac{2}{5}$ths; the heart, that is to say, works $\frac{3}{5}$ths of its time and rests $\frac{2}{5}$ths. Similarly after every expiration from the lungs there is a pause before the next inspiration begins. These periods of rest are necessary for the continued vigour of the organs. It is undoubtedly during the periods of repose that the energy expended in the immediately preceding activity is mainly renewed, and consequently, if, through want of the repose, the needed replenishment of energy did not take place, exhaustion would speedily follow. Now sleep is just another manifestation of this periodic character of living processes. Sleep affords the interval during which nervous energy expended during the waking hours is renewed. In the waking state the mind is being constantly appealed to. From all sides, by means specially of eye, ear, nose, and other sense organs, demands are made upon the attention of the brain, and during this waking state there cannot be a moment when the mind is not occupied somehow or other. All this means expenditure of energy, and consequent waste, which must be repaired. There, therefore, comes a time when this expenditure has reached a point when it is of advantage that it should cease, and the desire for sleep arises. The desire may, however, be fought and the activity of the brain continued *by demand. This activity by demand* means a greater than usual expenditure of nerve-force, a greater than usual degree, that is, of nervous exhaustion. But it is obvious that the time will speedily come, be the stimulus what it may, when the cells that are the source of the energy can no longer respond to the demand, and sleep will supervene, no matter how resolutely it may be resisted, and no matter what objects are brought before the mind with a view to retain its attention. Remarkable instances of this fact are given, such as those of gunner boys falling asleep during the height of an action, owing to the fatigue caused by their labours in carrying ammunition for the gunner. A case is also reported of a captain of a warship, engaged in the last attack upon Rangoon, falling asleep, and remaining so for two hours beside one of the largest guns of his ship, the gun being served vigorously all the time. Instead of sleep supervening, however, it often happens that, when sleep has been kept off by great mental effort or strain for a considerable time, a condition of irritability is set up which prevents the access of sleep when it is at length desired.

It has been said that during our waking hours the mind is kept incessantly active by the demands made on it through the senses. Naturally, therefore, sleep is most readily obtained when the avenues of sense are closed, so that the mind is cut off from the distractions that throng upon it. Thus the closing of the eyes, and darkness, cut off distractions conveyed by the organs of sight, and with silence the ear is powerless to stimulate. It is recorded of a boy who had only one eye and one ear that were of any use, and who, owing to disease, was otherwise insensible to impressions from without, that the closing of his eye and the blocking up of his ear speedily put him to sleep.

The condition of the brain during sleep is one of considerable bloodlessness. There seems both to be a diminished quantity of blood circulation through the brain, and the speed of its movement is lessened; whether this is the cause of sleep, or is the result of diminished activity of the organ—less demand and consequently less supply—it is difficult to say. Probably it is rather an effect than a cause of sleep.

In sleep, then, the mind is cut off from the outside world. The question has arisen whether this is all, or whether sleep implies not only the interruption to the conveyance of stimuli to the mind by the avenues of sense, but also interruption to the activity of the mind itself. In a word, does the mind sleep too, or does it wake? On the answer to this question depends the explanation given of many very complicated and interesting facts, such as those of dreaming and somnambulism. Many maintain that the mind is quite inactive during sleep, when the sleep is good. If the mind is quite inactive during ordinary profound sleep, there can, of course, be no dreaming, since that implies an activity of the mind. So those who believe profound sleep to mean complete mental inaction, believe dreaming to be the mark of imperfect sleep, and to occur, therefore, when sleep is light, and specially in the stage between sleeping and waking. The main feature of

dreaming is that, however active the mind may be, the will is in abeyance, and ideas and imaginations throng through the mind without let or hindrance in uncontrolled disorder. They are ideas with which the mind has been previously occupied, and which come up perhaps accompanied with their old associates, perhaps with other old ideas, not, however, formerly associated with them. They are frequently suggested by external circumstances, a sound setting up a rapid train of ideas which rushes across the mind in the interval before the person is awakened by it. Or the suggestion may come from within—the pains of indigestion setting up dreams of terror, coldness of some part of the body suggesting to the sleeper that he has fallen into the water, and so on. Nevertheless it has happened that intellectual processes of a high order have been carried on in dreams. Opposed to the view that the state of mind during sleep is one of inaction, is that view which holds that the mind is always active, and that in sleep we are always dreaming, but that we do not remember our dreams unless we awake in the middle of them. It is the memory that is defective and fails to recall our dreams. This view offers a simple explanation of dreaming and of somnambulism.

Somnambulism is distinguished from dreaming by the fact that while a person may recall his dreams, the somnambulist has no recollection of anything said or done during sleep. Somnambulism may be in the very simple form of talking in the sleep, or may amount to getting up, walking about (this is what the word implies —sleep-walking), and engaging in various kinds of activity. Cases are recorded of men rising in sleep, dressing, and going out to their workshops or offices, of mathematicians working out obscure problems which had baffled them when awake, of lawyers writing out just and accurate opinions on difficult and intricate points of law, concerning which they had been unable when awake to form a decision, of poets writing some of their most delightful verses, of musicians composing their most successful pieces, and of people discovering property that had been long lost or mislaid past finding. The credibility of such feats is denied by some eminent men, and yet instances are given of such things being done. More than that, there are credible records of as marvellous feats being performed by persons who developed their power during attacks of madness, and of people displaying, during attacks of delirium due to fever, powers formerly unknown to themselves, and powers they no longer possessed when the delirium had passed. Thus Dr. Rush, an American physician, has recorded of a female patient of his who became insane after parturition, in the year 1807, that she "sang hymns and songs of her own composition during the latter stage of her illness with a tone of voice so soft and pleasant that I hung upon it with delight every time I visited her. She had never discovered a talent for poetry or music in any previous part of her life. Two instances of a talent for drawing," he adds, "evolved by madness, have occurred within my knowledge." Coleridge in his *Biographia Literaria* (p. 54, ed. 1870) relates the following case, which "occurred in a Catholic town in Germany a year or two before my arrival in Göttingen, and had not ceased then to be a frequent subject of conversation. A young woman of four or five and twenty, who could neither read nor write, was seized with a nervous fever, during which, according to the asseverations of all the priests and monks of the neighbourhood, she became possessed, and, as it appeared, by a very learned devil. She continued incessantly talking Latin, Greek, and Hebrew in very pompous tones, and with most distinct enunciation. . . . The case had attracted the particular attention of a young physician, and by his statement many eminent physiologists and psychologists visited the town and cross-examined the case on the spot. Sheets full of her ravings were taken down from her own mouth, and were found to consist of sentences, coherent and intelligible each for itself, but with little or no connection with each other. Of the Hebrew a small portion only could be traced to the Bible; the remainder seemed to be in the Rabbinical dialect. All trick or conspiracy was out of the question. Not only had the young woman ever been a harmless, simple creature, but she was evidently labouring under a nervous fever. In the town in which she had been resident for many years as a servant in different families, no solution presented itself. The young physician, however, determined to trace her past life step by step; for the patient herself was incapable of returning a rational answer. He at length succeeded in discovering the place where her parents had lived; travelled thither, found them dead, but an uncle surviving, and from him learned that the patient had been charitably taken by an old Protestant pastor at nine years old, and had remained with him some years, even till the old man's death. Of this pastor the uncle knew nothing but that he was a very good man. With great difficulty, and after much search, our young medical philosopher discovered a niece of the pastor's, who had lived with him as his housekeeper, and had inherited his effects. She remembered the girl; related that her venerable uncle had been too indulgent, and could not bear to hear the girl scolded; that she was willing to have kept her, but that after her patron's death the girl herself refused to stay. Anxious inquiries were then, of course, made concerning the pastor's habits; and the solution of the phenomenon was soon obtained. For it appeared that it had been the old man's custom for years to walk up and down a passage of his house, into which the kitchen door opened. and to read to himself with a loud voice out of his favourite books. A considerable number of these were still in the niece's possession. She added that he was a very learned man, and a great Hebraist. Among the books were found a collection of Rabbinical writings, together with several of the Greek and Latin fathers: and the physician succeeded in identifying so many passages with those taken down at the young woman's bedside. that no doubt could remain in any rational mind concerning the true origin of the impressions made on her nervous system."

Dr. Abercrombie relates cases where attacks of somnambulism came on, not during night, but during daytime. During the attack—which lasted some time, then passed off, and at some later period returned—during the attack the persons were abstracted, and could do what was impossible to them after the attack passed off. One patient was an educated young lady, who, on recovering from her first attack, found she had lost all her former knowledge, and set to work to regain it. She was making progress when she was seized with a second, which left her with her former state of knowledge quite restored. This alternation went on for four years, one attack leaving her without her former knowledge, and the next restoring it. In this case there was shown what is called **double consciousness**, that is, things or persons that may have been seen, or things that may have been heard, during an attack were not remembered when the attack passed off, but were recalled during a succeeding attack. In the same way, anything seen or learned in the interval between two attacks was entirely forgotten in succeeding attacks, but was easily remembered in the intervals.

Thus, during somnambulism mental processes of a high character may go on, but they leave no recollection behind them.

A curious circumstance is that a person walking in sleep will move round obstacles in his path, and guide his course just as if he were fully awake and fully conscious of all his movements. This may be explained by reflex action (see p. 246), the objects making impressions on the eyes, and those impressions through the nervous ganglia at the base of the brain stimulating in a habitual way certain centres for movement. Often, however, somnambulists walk into dangers that cause their death.

The ordinary forms of sleep-talking and sleep-walking are common enough in children.

CHAPTER XIII.—THE SENSES AND SENSE-ORGANS.

The Conditions of Sensation.—The senses are the avenues by means of which information reaches the individual regarding the condition of his own body, and concerning the outward world which surrounds him, and of the manner in which it affects him. Every living being, even the humblest, is not a mere separate existence, having a life of its own and independent of everything else; it is a part of a greater existence; and its value is estimated by the nature of the relations it bears to that great world of things of which it is but a mere speck. The most elementary living things have no nervous system, no special apparatus for communicating outwardly. They are little masses of irritable jelly-like living material (protoplasm), capable of acting as a whole, and with no part of their substance devoted to special purposes. An advance in this structure is perceived when a living thing shows evidence of having one part of its body devoted to the discharge of one duty and another part to the performance of another duty. The rudiments of a nervous system are found in some of the lowest animals, where one cell readily affected by certain agencies—contact with foreign material, for example—is situated near the surface of the body and communicates by a slender thread with a cell, capable of contracting, placed deeply in the body. Whenever the cell on the surface is affected sufficiently, the irritation of its substance that results is communicated along the thread to the deep cell, and excites it to contract, so that the body of the organism is moved. One cell is, as it were, on the look-out, and the business of the other one is to act on receiving information. Such a simple arrangement is sufficient for an elementary organism. But animals higher in the scale are affected in so many different ways by so many different agencies that a further subdivision of labour becomes necessary. One man may be a sufficient watch on the top of a small fort, but a large town needs a multitude of watchmen, each with his own particular duty and his own special post. So in the higher animals and man certain organs are set apart to give information regarding things the body comes in contact with, their hardness, their degree of heat, &c., all that is included under the sense of touch; another organ is set apart to give information about smell, another to inform regarding taste; another organ has as its business the duty of being on the look-out for light and colour, another for taking knowledge of sounds. The senses are thus the outposts of the mind, disposed along its walls to take note of and report to head-quarters anything that comes within the range of their duty. Without them man could have no knowledge of the outward world and could hold no relations with it. On the information they supply depends, in great measure, the nature of his action.

There is thus a number of **special sensations**, touch, taste, smell, seeing, hearing, to which is added the muscular sense, by means of which information is supplied regarding outward things and forces. Besides these, however, there is a number of **common** or **general sensations**, the need of which arises from the highly complicated structure of the higher animals. The feature of such higher animals is the multitude of different organs in the body, each performing its own part of the general work required for maintaining the life and vigour of the animal. These organs must all work in harmony, and are in communication with one another. It is necessary that the individual should have some means of knowing whether the harmony is being maintained, and should have some warning if any organ is doing bad or indifferent work. Such information is supplied by common sensations. Thus a feeling of comfort informs of general well-being; a feeling of hunger or thirst informs of the need of certain substances to maintain nourishment; a sense of discomfort informs of some disturbance, and so on.

The essentials of a sense-organ are well shown in the rudimentary forms of a nervous system, where there exists (1) one cell so situated that on it the impression is made, and (2) a nerve thread to carry the impression to (3) a cell whose business it is to receive the impression, and take cognizance of it in some way or other. These three elements are necessary for a sensation. (1) There is a special structure adapted for being affected by a particular kind of influence. Thus the eye is an organ specially formed for being stimulated by the action of light, while the ear is uninfluenced by light but is stimulated by the waves of sound, and so on. The special structures are called **terminal organs**. From the special structure, whatever it may be, (2) a nerve proceeds which is in direct communication with (3) nerve-cells in the brain in the region of consciousness. This last is important to notice. The nerve-centre to which the impression, made on the terminal organ, is conveyed by the nerve, must be situated in the brain, if the impression is to give rise to a sensation. Suppose the impression for some reason or other is arrested in the connecting nerve, no sensation will result. Thus the nervous chain necessary for a sensation is not identical with that described on p. 246 as necessary for a reflex action. A man who has had his spine injured. and is thus paralysed in both legs, does not feel a severe pinch of the skin of either leg, but probably the pinch causes the leg to be spasmodically jerked. An impression has been made on the skin, which has been transmitted to a nerve-centre. But the nerve-centre is in the cord. The injury to the spine has prevented the impression being conveyed up the cord to higher centres in the brain. Thus, though the impression has been quite sufficient so to stimulate a nerve-centre in the cord as to produce a marked reflex act, the man has been unaware of the pinch; he has had no sensation. A sensation. then. cannot be produced unless the influence has been transmitted to a higher centre in the brain, and has there excited a change of which the individual becomes aware. An impression may be duly made upon a terminal organ. but it cannot properly be called a sensation until the person becomes conscious of it. *A sensation may, therefore, be* *defined as the consciousness of an impression.* Now, if this is understood, it is easy to perceive that sensation may be abolished in various ways. Take, as an example, the sense of sight. A person may be blind, as we all know, because of some injury or disease of the eye, because, that is, of something wrong with the terminal organ; but disease of the eyes is not the only cause of blindness. Another person might have perfect eyes, and yet have no sight. The nerve leading from the eye to the brain, the chain of communication, might be interfered with, destroyed, for example, by the pressure of a tumour, and, therefore, though light duly fell upon the eye and produced there its wonted effect, no knowledge of it would exist because of the rupture of communication—the impression could not be conveyed to the brain. In a third way a person might be prevented from seeing. Suppose the eye and its nerve unaffected, but the centre in the brain destroyed by the progress of some disease, the impression duly made on the terminal organ and carried along the nerve would reach a disorganized centre, which could not receive it, and no consciousness of sight would arise. But there are instances of failure to see, illustrating well the necessity for activity of the centre, not dependent upon any disease. Lift the eyelid of a sleeping man, and hold a lighted candle in front of the eye, an image of the candle flame is properly formed on the back of the eye, an impression is duly conveyed along the nerve to the centre, but the centre slumbers and there is no conscious sight. A man is walking through the streets engrossed in thinking over something; a friend walks straight towards him, and the person is apparently looking directly at his friend, but does not notice him, and would pass on did his friend permit. His friend's face and figure made their usual impression on the eye, which was properly transmitted to the conscious centre, but that centre was already occupied, and the impression failed to arouse a consciousness of its presence. The same facts might be illustrated in connection with any other sense, but enough has probably been already said to show what are, in general, the conditions of any sensation. Sensation, then, is the result of a change occurring in a centre in the brain, and yet when the skin is pinched we refer the impression to the skin, though it is in the brain that it is actually perceived. We think it is our ears that recognize sounds; in reality it is only the brain that takes note of them as such. This habit of referring the sensation to the terminal organ which first received the impression is the result of education and habit. When we see a light, what we are conscious of is a change in a brain-centre, and yet we refer it outwardly. If the optic nerve be irritated by a current of electricity or by a blow, we see flashes of light as vivid as if lights actually danced before our eyes. Impressions have reached the centres for seeing, coming along the ordinary channels, and produce the same changes as lights should cause. In this case, however, we know the cause of the colours, and correct the conclusion we would otherwise make. The seeing centre itself may be irregularly stimulated, by some condition of the blood, for example, and the person may see things which appear as real as if they were actual external existences, but which have only a temporary existence in his disturbed brain. Thus the man in *delirium tremens* sees fantastic figures dancing and making grotesque faces at him. His seeing centres, excited in an unhealthy way by alcohol, are of themselves producing changes which, in healthy circumstances, ought only to be aroused by real things external to him. The changes in the brain have, in this case, nothing corresponding to them outside, but the brain, nevertheless, refers them to the outside as usual, and they, therefore, appear to be real things. The man's judgment being otherwise also warped by the alcohol, he cannot correct his impressions, and is consequently victimized by them.

Subjective Sensations.—The above illustrations of the functions of the brain centre in the perception of an impression will make clear what is meant by subjective sensations. All our healthy experience is that, if we have a sensation, its cause is something external to the part where we localize the sensation. If we have a sensation of sweetness, it is because something sweet has been put into the mouth, if we have a sensation of light we refer its cause to some luminous body outside of us, if we have a sensation of touch we infer that something outside of us is in contact with some part of our body. We always refer the sensation to some object in the world outside of us. But, as we have seen, this object outside of us creates an impression which is only the first of a series of changes, of which the last occurs in some nerve-centre in the brain, and it is the last of the series that we are really conscious of. If for some reason the change occurs in the brain centre, when there is nothing corresponding to it in the external world, we still have the sensation, but inasmuch as it arises wholly within ourselves it is called a subjective sensation.

Fusion of Impressions.—It is a feature of all the senses that when they are excited by a series of impressions, in which one follows the other very quickly, they are unable to distinguish the different impressions. The series becomes fused together, and the sensation is of a prolonged impression. Thus, if the finger be gently pressed on the edge of a toothed wheel, with the wheel going very slowly, the contact of each separate tooth is distinctly felt; but when the wheel is made to turn rapidly one loses the sensation of the separate teeth, and the feeling is of an uninterrupted kind. Again, every child knows that if a piece of string, which has been on fire at one end, be whirled rapidly in the air, the appearance of a wheel of fire is produced. The one point of fire becomes a circle. This sensation is produced by a rapid series of impressions. From every point of the circle, described by the glowing end of the string, from point after point of it in quick succession, an impression reaches the eye of the glowing point as it travels round. But the different impressions follow so rapidly after one another that they are not separately distinguished in the mind, which thus becomes conscious of a continuous circle of light. It is the same with sound. If an instrument be made slowly to emit a series of sounds, each sound of the series may be recognized separately; but if they be produced with a certain rate of rapidity, one sound is heard before the impression of the one preceding has died out, and a continuous instead of an interrupted sound is heard.

Now the explanation of this fusion of impressions is the same for all the senses. It is that the sensation lasts longer than the stimulus producing it. A flash of light in the darkness may last for a very small fraction of a second, but the effect on the eye does not vanish with the flash. It continues for a very brief space of time longer, and if a second flash be produced it may again excite the eye before the first impression has faded, and so the two become blended. Most people have noticed that if a shrill sound, say a railway whistle, has been prolonged for some time, they are doubtful of the exact moment when it ceased. The sound appears to ring in their ears some seconds after it actually stopped. If it had begun again before the ringing had left their ears, probably many would not observe that it had stopped for an instant. It would seem to have only become feebler for the moment.

TOUCH.

The Organ of Touch.

The **organ of touch** is situated in the skin throughout its whole extent, and in the mucous membrane of the mouth and nostrils. On p. 227 the structure of the skin is described, and the two layers of which it consists are noted. Fig. 97 also illustrates the difference between the deep layer of the true skin, the surface of which is thrown into projections or papillæ, and the superficial layer or epidermis which covers over the papillæ and dips in between the papillæ. In fig. 98 a highly magnified view of one such papilla with a touch corpuscle is shown. It is only in the deep layer that blood-vessels and nerves are found. The nerves terminate in many cases in a peculiar way. In many of the papillæ are oval-shaped bodies about $\frac{1}{300}$ inch long, formed apparently of layers of fibrous tissue. A nerve-fibre (*d*) winds round this body and finally enters it. These are called **touch-bodies** or **tactile corpuscles,** and are found in the skin of fingers and toes. In the skin of the front of the finger they are specially numerous, there being, it is calculated, 50 such corpuscles in an area $\frac{1}{25}$ inch square. They are found in other situations also, in the skin of the forearm and breast, on the edges of lips and eyelids, but more scantily. In the tissue under the skin of the hand and foot of man are other bodies, called **Pacinian corpuscles,** larger than touch-bodies, the largest being $\frac{1}{20}$ inch long. Each one is placed on the end of a nerve-fibre, which is like a stalk to it, the fibre passing directly into the centre of the corpuscle. Such a Pacinian corpuscle is shown in fig. 99, where the corpuscle is shown in section, as consisting of a central soft core *m*, into which passes the central rod or axis-cylinder *n′* of a nerve-fibre *n*, the axis-cylinder terminating in the upper end in an irregular expansion *a*. The main body of the corpuscle is seen to consist of very numerous layers or tunics (*c*, *d*) of fibrous connective tissue. When the nerve pierces the capsule it is clothed with medulla (*f*), but, soon after, the medulla ends and only the axis-cylinder plunges into the core. Such bodies are found on the branches of nerve running in the loose tissue beneath the skin of the palm of the hand and sole of the foot, to the extent of about 600 in each hand and foot. They are found in the neighbourhood

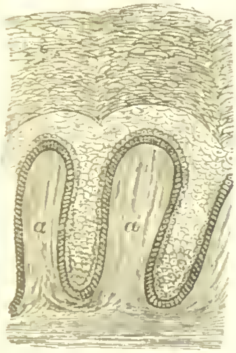


Fig. 97.—Vertical Section of Skin, showing Papillæ (*a*).

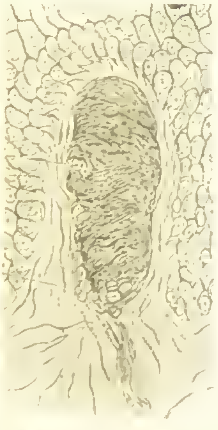


Fig. 98.—Magnified View of a Papilla of Skin, with a Touch Corpuscle.

of joints and in other situations. In the papillæ of the red border of the lips is found a third form of nerve-ending, called **end-bulbs**, formed of a small capsule of connective tissue in which one or more fibres of a nerve terminate among soft material. Besides these three special forms of nerve-endings in the skin, there are the simple terminations of filaments of axis-cylinders of nerves in the deepest layer of cells of the epidermis in the form of a net-work. In all cases the nerve-endings never reach the surface. Any impression must be communicated to them through the cellular layers of the scarf-skin.

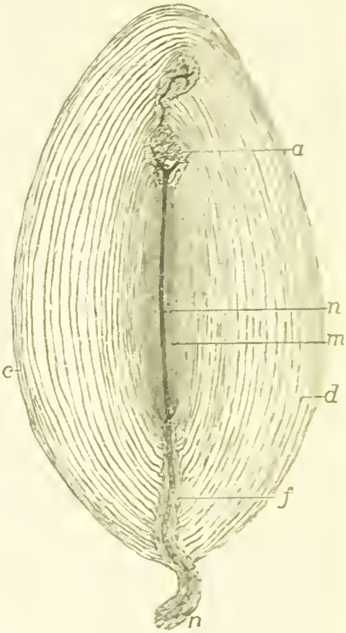


Fig. 99.—Pacinian Corpuscle.

The Sense of Touch.

The **sense of touch** is aroused by stimulation of the nerve terminations, already described, either by mechanical means or by heat or cold. When we lay our hand on anything, the mere mechanical contact with the body produces a sensation of touch, and if the body be warmer or colder than the hand a sense of heat or cold is aroused. Touch includes three things: (1) the sense of contact, (2) the sense of pressure, (3) the sense of heat and cold.

(1) The **sense of contact** is the most important element in touch. By it we gain information as to the form, size, and other characters, smoothness, hardness, &c., of external bodies. The sensitiveness of touch varies in different parts of the skin. Where the scarf-skin (epidermis) is thinnest it is most acute; where it is

thickest it is more dull. The absence of epidermis altogether does not render the part more sensitive to sensations of contact. The direct contact with the unprotected true skin occasions pain, which effectually masks the feeling of contact. The tips of the fingers, the red border of the lips, and the tip of the tongue are the most sensitive parts. Experiments have been made on the degree of sensibility of various parts to touch, by using a pair of compasses with points blunted by pointed pieces of cork, and determining how much the compasses required to be open for the impression of each point to be felt. If the two points were very near, the sensation was of one point only, and in order to produce the sensation of two points the ends of the compasses had to be separated by varying distances according to the part of the skin experimented on. The result showed that two points could be distinguished by the tip of the tongue though they were only $\frac{1}{24}$ inch apart, by the tip of the forefinger if $\frac{1}{12}$ inch apart, by the red surface of the under-lip if $\frac{1}{8}$ inch apart, by the tip of the nose when $\frac{1}{4}$ inch apart, by the palm of the hand if $\frac{5}{12}$ inch apart, and that the points of the compasses required to be separated $1\frac{1}{8}$ inch to be perceived as two, when placed on the back of the hand, while in the middle of the thigh they required to be separated $2\frac{1}{2}$ inches.

This power of distinguishing two sensations whose situations are separated from one another by a very small interval of space, is dependent upon what is called **localization of touch**. There is not only the perception of a contact, but the reference of the contact to a particular locality, to a particular part of the body. This power of localization is, of course, gradually developed by exercise, but it cannot be exercised by any portion of the skin where the terminal organs of touch are not numerous; and it is noticeable that two points can be distinguished, when separated by a small interval, where touch corpuscles are most numerous. Now it is this power of localization that makes it possible for much valuable information to be supplied by touch. By touch of the hand a person can tell, with the eyes shut, a round from an oval body, but let a round body be pressed against the skin of the back and then an oval body, and the person will find it very difficult to distinguish them. This is because, in the case of the hand, two impressions need to be separated by only a small space to be distinguished from one another, and thus with one touch of the hand numerous separate impressions are obtained which are fused in the mind, and from which the idea of the shape of the body touched is constructed. But from the skin of the back only one large vague confused impression is obtained, and thus the shape of the touching body is not easily appreciated.

(2) The **sense of pressure** is different from the sense of contact, for sometimes those parts which are less acute for mere sensations of touch are more correct in gauging pressures. It is by the sense of pressure that we estimate differences of weights. Another element is introduced, however, in judging of weight, when the weight is taken in the hand, and the hand moved up and down. The weight offers resistance which the muscles require to overcome, and this calls forth what has been called **muscular sense,** a sensation produced by the muscles, caused by the resistance offered to their movement.

(3) **The sense of temperature.**—The skin also judges of heat and cold, but its judgments are in this case liable to serious error. If one hand be very cold and the other very warm, and both be placed in the same basin of tepid water, the warmth of the water will be very different to each hand. To the warm hand it will appear cold, and to the cold hand warm. We cannot, therefore, judge absolutely of temperature. Then again the thickness of the scarf-skin seems to affect the sensitiveness to heat, for parts with thin epidermis can bear less heat than parts with thick epidermis.

It is probable that the sensation of contact and that of temperature are not produced by an impression on the same but on different nerve-endings. That is to say, it is probable that one kind of nerve-ending is influenced by contact, and another kind by temperature. One reason for this opinion is that parts of the skin most sensitive to touch, namely the tips of the fingers, are not most sensitive to heat or cold. There are also experiments which seem to show that one part of the skin is more readily affected by heat, and another by cold.

Pain is an excessive stimulation of the sensory nerves, and in it all finer sensations are lost. Pain at once takes the place of other sensations, at that part of the skin so deprived of the epidermis as to lay bare the true skin.

The sense of touch supplies information according to the degree of its education. A common instance of this is the use of the blind alphabet. An untrained person cannot distinguish the form of the raised letters; all is to him confused and indistinguishable.

A curious illusion of contact is shown in an experiment of Aristotle's. Place a marble between two fingers, so that it touches one side of one finger and the other side of the other finger. There is the sensation of one marble. Now cross the one finger over the other so that the marble is supported by the other sides of the two fingers, the sides not usually opposed to one another, and roll the marble between the two fingers, the impression of two marbles will be received, more particularly if the eyes are shut. Probably this is the result of habit, for the two surfaces of the fingers could never make contact with one object, unless the fingers were crossed in this unnatural way. Usually an impression on each surface at the same time would arise from two different bodies, and as this has always been the case the habitual impression is aroused even when, by crossing the fingers, one body is made to touch both surfaces at the same time.

TASTE.

The Organ of Taste.

The **Tongue and Soft Palate** are the seat of the organ of taste, which consists, like that of touch, in a particular mode of nerve termination. The tongue is composed mainly of muscular fibres running in various directions, and freely supplied by nerves and vessels. It is covered by mucous membrane similar to that lining the mouth, which contains glands in the deeper layers. The surface of the mucous membrane is thrown into irregular projections, called **papillæ**, of various forms. The **filiform papillæ** are very short, fine, hair-like processes, which are exceedingly numerous over the whole surface. The **fungiform papillæ** are broader and mushroom-shaped, and are scattered over the surface. They often project as red points when the rest of the tongue is white and furred. The **circumvallate papillæ** are the largest of all, and the least numerous. They are so called because they consist of a fungiform papilla surrounded by a fold of the mucous membrane. They present the appearance of being walled round. They are found near the back of the tongue, being ranged in two lines, passing from a point in the centre of the surface towards the sides. There are only about a dozen of them altogether. The papillæ all contain twigs of vessels and branches of nerves, and are covered by the epithelium of the surface. In the circumvallate papillæ are peculiar structures called taste buds. Fig. 100 shows a section of such a papilla, in which A is the centre, and B B sections of the surrounding fold. A trench is seen to separate the centre from the

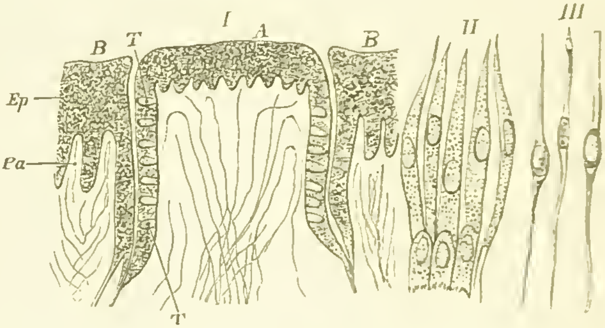


Fig. 100.—Section of Circumvallate Papillæ of the Tongue—highly magnified.

I A, section of the central papilla. B B, section of the surrounding elevation. *Pa*, papilla of the true skin. *Ep*, layer of stratified squamous epithelium. T, taste buds. II and III represent very highly magnified views of cells of the taste buds.

surrounding fold, and at the sides of the central papillæ, in the deep parts of the trench, are a number of flask-shaped bodies (T T). These are the taste buds. They are barrel-shaped, and are formed of stave-like epithelial cells, represented in II of the figure. In the inside of the buds are finer cells, represented at III. The mouths of the buds open into the trench, and the ends of the fine inner cells project through the flask mouth for a short distance. The taste bodies are connected with nerve-fibres, and it is supposed they are readily excited by sapid substances and transmit the impression along the connected nerve.

The tongue is supplied with sensory fibres by two nerves, the glosso-pharyngeal, a branch of the eighth cranial nerve (p. 279), and a branch of the fifth cranial nerve (p. 278)—the gustatory branch. The former confers taste on the back part, and the latter on the front part of the tongue. Branches of the former also pass to the soft palate and neighbouring parts, and confer taste on it. The motor nerve of the tongue is the hypoglossal (p. 280).

The Sense of Taste.

The **sense of taste** is excited by stimulation of the mucous membrane of the tongue and palate affecting the terminations of the nerve-fibres and causing impressions to be transmitted to the brain. The stimulation seems to be a chemical one; and the substances must be in solution to produce taste. A dry condition of the mouth is not favourable to taste, and powders are not tasted till dissolved by the juices of the mouth. Various kinds of substances are capable of producing the stimulus; acid substances, alkaline and saline substances do so. Acid tastes are perceived by the fore part of the tongue, bitters by the back part and not by the fore part. Sweet and salt tastes are perceived by both. Stimulation of the nerves, for example by electricity, and without the presence of any tasty body, will excite sensations of taste. The nerve-centre for taste receives an impression transmitted by the nerve, and has no means of distinguishing between such impressions and others excited in a regular way. Similarly morbid conditions of the body may excite sensations of taste.

The taste of many substances is got rid of with difficulty. This may be due to the extreme sensibility of the nerve terminations to some substances. Thus 1 part of sulphuric acid in 1000 parts of water will be detected by the taste, and it may be that the taste remaining in the mouth is due to traces of the substance. Like other senses, that of taste may become fatigued. Repeated tasting of one substance rapidly deadens the sensibility, probably because of over-stimulation.

The sense of **flavour** is something more than taste. Flavour is a conjunction of both smell and taste. Thus, if the eyes of a person be bindfolded, and the nostrils firmly held, the person will be unable to distinguish between an apple and an onion, if one be rubbed on the tongue after the other. As soon as the nostrils are open the difference is perceived. In a similar way a common cold, causing blocking of the nose, interferes with the sense of flavour, as it abolishes smell.

SMELL.

The Organ of Smell.

The **Nostrils** contain in their mucous membrane the structures devoted to the sense of smell. Reference to fig. 14, p. 42, shows the cavity of the nostrils so far as formed by bone. The roof of the cavity is formed by the ethmoid bone, the upper surface of which forms part of the floor of the brain cavity, so that this horizontal plate above separates cranial cavity from the cavity of the nostrils. Part of the side walls of the nostrils, as low as the floor of the cavities for the eye (see p. 42), are formed by light scroll-like prolongations of the same ethmoid bone, the remainder of the side walls being formed of part of the upper jaw-bone. A central perpendicular plate of the ethmoid divides the upper part of the cavity into a right and left portion, and this division is continued downwards by the ploughshare bone (p. 44), and completed by gristle. The bony palate forms the floor of the nostrils. There is an opening to each nostril behind, into the back part of the throat, as well as in front. The walls of the cavities are lined by mucous membrane, richly supplied by vessels and nerves. The nervous distribution is shown in fig. 101, where branches of the fifth cranial nerve are seen traversing the cavity and passing over its walls. The nerves of smell proper, however, spread in a thick brush over the upper and middle scroll-like bones of the outer wall (fig. 101) and over the upper part of the inner wall. They are found in the mucous membrane. These nerve-fibres are derived from the first pair of cranial nerves—the olfactory (p. 276), which rest on the upper surface of the ethmoid bone, and send branches through openings in its horizontal plate, which, because of the many perforations in it, is called the **cribriform** plate. It is in the mucous membrane of the uppermost part of the cavity of the nostril that the nerve terminations of smell proper reside. The other nerves supplying the nostril are those of common sensation only. The olfactory mucous membrane is called the **Schneiderian membrane**, and it differs

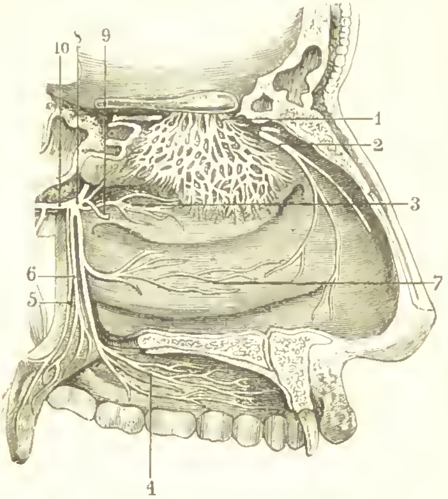


Fig. 101.—Distribution of Nerves over interior of Nostrils, outer wall.

1, branches of nerves of smell—olfactory nerve. 2, nerves of common sensation to the nostril. 4, 5, 6, nerves to the palate springing from a ganglion at 3. 7, 8, 9, branches from one of the palate nerves to nostrils.

from the mucous membrane of other regions of the nostrils in this, that the epithelium lining the merely respiratory region of the nostril is columnar and ciliated, while that of the olfactory region is lined by epithelium of a special character. The cells are of two kinds: (1) long columnar cells, non-ciliated and flattened like the handle of a knife; and (2) between the first are oval cells with a long tapering process from each end of the oval. One process projects beyond the free surface, and is probably affected by the smelling substance, while the other process passes into the depth of the mucous membrane and becomes connected with a filament of the olfactory nerve. These are the true olfactory epithelium, the former kind being merely supporting cells.

The Sense of Smell.

The **sense of smell** is excited by the contact of particles contained in the air with the terminations of the fibres of the nerve of smell. But the terminations of the true nerve of smell are found, as we have seen, only in the upper parts of the nasal cavities. In the lower parts are terminations of nerves of ordinary sensibility. These latter may be irritated by some substance, such as ammonia, resulting in a powerfully pungent sensation. This is not a true sensation of smell, but merely an irritation of the nerves of common sensibility. In ordinary quiet breathing the air passes through the lower part of the nasal cavity, and the air in the upper regions is barely disturbed. If few of the odour-bearing particles are in the air, they may never reach the true olfactory region, and no smell will be felt. In such a case, if a sudden sniff be made, the air is forcibly drawn into the nostrils, passes up even into the upper chamber, and thus a faint smell becomes readily perceived.

The sense of smell is extremely acute. According to Valentin $\frac{3}{100,000,000}$ of a grain of musk can be distinctly smelled. Like taste, the sense of smell becomes readily fatigued. Thus, after remaining a time in an atmosphere whose smell appears strong when we first enter it, we gradually fail to perceive the odour, and it is only when we have passed out again to the fresh air that we again perceive the difference. Smell is related to taste in the perception of flavours, as already noted under TASTE. The swelling of the lining membrane of the nostrils, caused by a cold, abolishes smell, probably both by preventing the entrance of air to the upper parts of the chambers, and by burying and obscuring for a time the endings of the terminal organ.

Sensations of smell may be excited by stimulation of the centres for smelling in the brain, owing to some abnormal condition and not because of impressions produced on the terminal organ by any odoriferous particles.

SIGHT.

The Organ of Vision—The Eye and its Appendages.

The Orbit.—The eyeball is situated in a bony cavity called the orbit, formed by various bones of the head and face (see p. 43). The cavity is padded by a loose fatty tissue, the diminution in the amount of which aids in producing a sunken appearance of the eyes.

The **Eyelids** are formed of folds of skin, the outer surface having the structure of ordinary skin, the inner of mucous membrane. In the body of the lids is a layer of condensed fibrous material which maintains the shape of the lids. Nearer the inner than the outer surface of the lids is a row of glands, which open on the free edge of the lid and pass from there into the eyelid in a vertical direction. These are the **Meibomian glands.** The blocking of one of these glands by the material it itself produces leads to the formation of a sty. Towards the front of the free edge of the lids are the eyelashes, which are thick and capable of rapid growth, so that if one falls or is pulled out another quickly grows in its place. The inner lining membrane of the lids is very richly supplied with vessels and nerves. The membrane is called the **conjunctiva**. It is continuous with the skin at the free edge. After lining the inner surface of the lid it passes over on to the eyeball. In ordinary inflammation from cold it is this membrane, whose blood-vessels are engorged with blood, that is the seat of the redness and swelling, and it is because it continues forwards over the eyeball that the eye has its bloodshot appearance in such cases. Such inflammation is called **conjunctivitis**.

In the eyelids are muscular fibres which close the lids by their contraction.

The **Tear-gland** (lachrymal gland) and passages. Situated outside of the eyeball among the loose fatty tissue of the orbit in its upper and outer corner is the lachrymal gland. Like the salivary, it is a racemose gland. From it several little channels lead which open on the inner surface of the upper lid. The fluid produced in the gland passes out by these openings and flows over the eyeball. It is ordinarily just in sufficient quantity to keep the eyeball and lids moist, to wash off dust, &c. Having flowed over the eyeball the fluid collects at the inner angle of the lids. At this place in each lid is a little projecting point (**punctum lachrymalium**) in the centre of which is an opening. The openings communicate each with a small canal in the lid, which passes to the angle between the orbit and bridge of the nose, where is lodged a little sac—the **lachrymal sac**. The canal of both upper and lower lids joins this sac, and from it there passes a channel—the **nasal duct**, lodged in a canal in the bone, which leads into the lower part of the nostril. The fluid which has flowed over the eye is drained off by these canals into the nose. The lining membrane of the eyelids is continuous through these canals with that of the nostrils, and thus redness and swelling of the nasal membrane, caused by cold, are apt to pass upwards and inflame the eyelids. The canals are often blocked by inflammation, and the fluid collects in the corners of the eyelids and flows over on to the cheeks.

The secretion of the lachrymal gland is under the control of the nervous system. Anything that irritates the eyelid leads to stimulation of sensory nerves, the impression passes to a nerve-centre in the base of the brain, from which nervous impulses travel to the gland leading to increased flow of its secretion. The first act in the process may be the excitement of sensory nerves in the nostril, as by the smelling of pungent salts. The stimulation of the same nerve-centre results, with its consequences of increased flow. A mental emotion, joy or grief, may stimulate the centre and produce similar results. In such cases the fluid is produced is such quantity that it cannot escape by the lachrymal canals quickly enough, and the excess rolls over the cheeks as tears. This is the explanation of weeping. Some people are "dry-eyed" in times of deep grief or other emotion. The explanation of this is as simple. The nervous influence acts on the centre in a precisely opposite way, so that instead of it stimulating the flow of blood through the gland and otherwise exciting increased activity, the nervous impression arrests the activity, so that less fluid than usual is produced. In a similar way the emotion which produces blushing in one man leads to pallor in another. In the former case the nature of the nervous effect is to permit a greatly increased flow of blood through the vessels of the face, and therefore redness of the surface, in the latter case it diminishes the natural flow, therefore there is less blood in the part and consequently less colour.

The **Eyeball** is a globular chamber. Its walls consist of several layers. The outermost layer is called the **sclerotic**, is a tough fibrous coat formed for protection and maintaining the shape of the ball, and is thicker behind than in front. This coat is white in appearance, and is the part easily visible to which the phrase "white of the eye" is applied. In the very front of the globe the sclerotic is abruptly transformed into a transparent portion which is circular and which forms a window through which one can see into the interior. This is the **cornea.** The sclerotic is supplied with vessels and nerves, but the cornea, though containing nerves, has no blood-vessels. It is composed of layers of fibres with numerous minute spaces between the layers, in which connective tissue cells lie. The cells send off numerous processes which communicate with one another, so that the substance of the cornea is traversed by the branches of the connective tissue corpuscles. No doubt by this living material, in lieu of vessels, the nourishment of the cornea is maintained without its transparency being interfered with. The visible part of the white of the eye is covered, as already noted, by the delicate membrane, the conjunctiva, reflected from the inner surface of the lids. This membrane has the structure of mucous membrane, fibrous tissue covered by stratified squamous epithelium. But when the conjunctiva reaches the cornea, only its epithelial layers are continued over the cornea. In inflammation of the cornea blood-vessels rapidly shoot into its substance from the conjunctiva around.

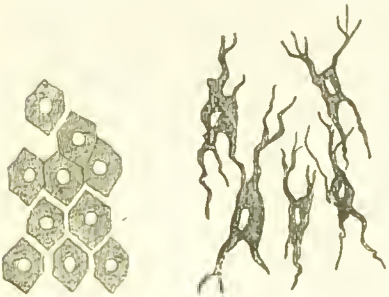


Fig. 102.—Different Kinds of Pigment Cells from Choroid Coat of the Eye.

Lining the inner surface of the sclerotic is the second coat of the eyeball—the **choroid**. This is essentially the blood-vessel coat of the eyeball. It contains a multitude of small arteries and veins whose connecting capillaries form a very close net-work. Connective tissue surrounds the vessels, and in the tissue are branched cells so loaded with colouring matter as to be quite black. Their appearance is shown in fig. 102. The front part of the choroid terminates, about the place where the sclerotic passes into the cornea, in a series of ridges, the **ciliary processes**. The circular space, thus left in front by the termination of the choroid, is occupied by the **iris**, a round curtain, the structure seen through the cornea, differently coloured in different individuals. In its centre is a round hole, the **pupil**, which appears as if it were a black spot. The margin of the iris is connected firmly with the eyeball all round, at the line of junction of the sclerotic and cornea.

The iris forms a sort of transverse partition dividing the cavity of the eyeball into two chambers, a small **anterior chamber**, extending from the front part of the iris to the back part of the cornea, filled with the **aqueous humour**, a fluid consisting almost entirely of water with a very small quantity of saline material in solution, and a large **posterior chamber**, filled with **vitreous humour**, a kind of fine transparent, colourless jelly. The iris consists of a framework of connective tissue, and its posterior surface is lined by cells containing pigment, which gives the colour to the eye. In its substance are bundles of involuntary muscular fibres, one set being arranged in a ring round the margin of the pupil, the other set radiating from the pupil like the spokes of a wheel. When the circular fibres contract the pupil is made smaller, but if these fibres relax the radiating fibres cause the pupil to dilate more or less widely. The object of this will be seen hereafter.

Just behind the pupil is the **crystalline lens**, resembling a small, very strongly magnifying glass, convex on each side, though more so behind. It is perfectly transparent in the healthy state. The front face of the lens is quite close up to the curtain of the eye, and the vitreous humour, occupying the posterior chamber, is closely in contact with its back face. But the lens is not loosely placed in the eyeball; it is inclosed in a capsule, the **suspensory ligament**, which not only retains it in position, but is capable of altering its shape. For the lens is elastic, its capsule is connected with the ciliary processes, and is kept usually tense, so that the lens is flattened somewhat by the pressure exerted on it. But all round the edge, where the cornea, sclerotic, and choroid meet, is a ring of involuntary muscular fibres, forming the **ciliary muscle**. When this muscle contracts it pulls forward the attachment of the suspensory ligament of the lens, whose pressure on the lens is consequently diminished, and the elasticity of the lens causes it at once to bulge forwards, and it becomes thereby more convex. The value of this movement will be understood immediately.

Reference to fig. 103 will render the position of the parts already described more intelligible. It represents the eye lying in its socket, partly covered by the eyelids, and completely opened up by a cut from front to back. In the figure, muscles (P, N) of the eyeball are shown, and a meibomian gland opened up (Q, R) is represented in each lid. A is the cornea which, at the place across which the lines from F and G pass, joins the white sclerotic (H). The cornea closes the front of the anterior chamber (B), which is filled with aqueous humour. and the back wall of which is formed by the curtain of the iris (D). In the middle of the back wall is the opening of the pupil (C), through which is seen the lens (E). F and G point to the region of the ciliary muscle and ciliary processes, the forward termination of the choroid coat (I).

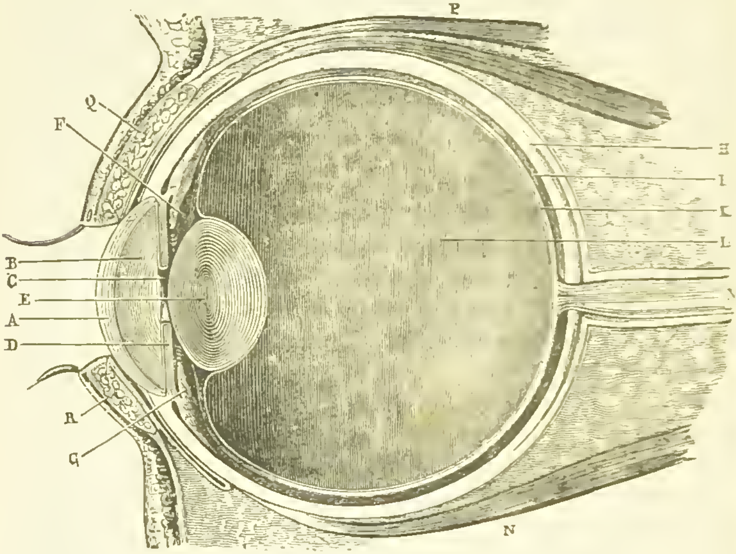


Fig. 103.—Representation of a vertical cut through the Eyeball in its Socket. For description see text.

Behind the lens is the posterior chamber (L), filled with vitreous humour.

Our description is not yet complete, however. The eyeball, at least the posterior chamber, has an innermost lining, called the **retina** (K). The **retina** lines nearly the whole of the inner surface of the posterior chamber, lying on the choroid coat. It is, consequently, with the retina that the vitreous humour is in contact. The retina is the nervous coat of the eye; it really forms the terminal organ (p. 292) of the sense of sight. It is a very thin, soft, white membrane. If the fresh eye of a sheep or ox be opened, and the jelly-like vitreous humour removed, the retina will be seen and easily separated, as a pulpy membrane, from the dark coloured choroid on which it rests. But it does not separate completely. At one spot it is bound down. This spot is the entrance of the **optic nerve.** The nerve (M) comes from the brain (p. 276) and pierces the eyeball at the back, not quite at the middle, but about $\frac{1}{10}$th of an inch to the inner side, the nose side. The fibres of the nerve are distributed in the retina. The retina does not extend quite to the front limits of the posterior chamber, but stops short, in a scalloped border, the **ora serrata**, a little way behind the ciliary processes.

Though the retina is extremely delicate, its structure is very complicated. If a piece of the retina, representing its whole thickness, is examined under a microscope it shows a structure exhibited in detail in fig. 104. The part resting on the choroid coat consists of six-sided granular nucleated cells filled with colouring matter (fig. 102). Outside of that is a layer called **Jacob's membrane**, containing bodies termed **rods** and **cones.** To this succeeds a layer of nuclear bodies developed in fibres continued from the rods and cones. Outside of these a granular layer, and other nuclear bodies, &c., as represented in fig. 104. The two layers nearest the surface of the retina, nearest the vitreous humour, therefore, are a layer of nerve-cells and nerve-fibres. In the retina, vessels ramify in the region between the inner granular layer and the surface next the vitreous. The vessels are branches of the artery that enters in the substance of the optic nerve.

At the entrance of the optic nerve the retina contains no rods or cones. In the retina at a point exactly in the middle of the back wall, therefore directly opposite the centre of the pupil (about $\frac{1}{10}$th of an inch to the outer side of the optic nerve entrance), there is a yellowish spot of an oval shape, the **macula lutea**, or **yellow spot** of Soemmering, which exhibits a central depression (the **fovea centralis**). At this part the retina is very thin, all the layers being very much diminished in thickness, except that of the rods and cones, the layer of nerve-fibres being absent. In the layer of rods and cones marked differences from other parts also exist, for rods are scarce and cones are very close and numerous.

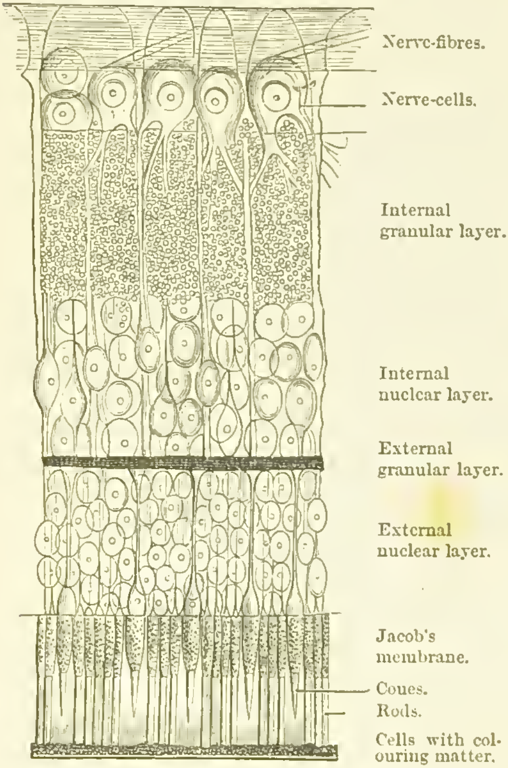


Fig. 104.–The Microscopic Structure of the Retina.

The rods and cones are to be regarded as the peculiar modes of termination of the nervous filaments in the eye, just as the taste buds are the modes of termination of the nerve of taste in the tongue (p. 302), just as the touch-bodies are the terminations of the nerves in the skin (p. 297), and just as epithelial cells of a peculiar shape form the terminations of the nerves of smell in the nostrils.

The Sense of Sight.

The Perception of Light.—The agent that excites the terminations of the nerve-fibres in the retina is light. The sensation of light is produced in the brain by impulses reaching certain nerve-centres and coming along the optic nerves. These impulses are, in ordinary circumstances, sent along the optic nerves by the retina, and are communicated to the retina by the vibrations of ether which are held to be the physical cause of light. But any excitement of the optic nerve, if it be passed on to the brain, will produce a sensation of light. Thus electrical stimulation of the optic nerve will do so, because it, equally with the usual stimulus of light, sets up changes in the brain cells, which occasion the sensation. Mechanical stimulation, of which the commonest form is "a blow on the eye," will also excite the nerve and produce sensations of light. It is the terminations of the nerve-fibres—the rods and cones, not the fibres of the nerve themselves, that are excited by light, for light falling directly on the optic nerve alone has no effect, while the feeblest glimmer of light will excite the retina and lead to a luminous impression.

The whole surface of the back of the eye is not, however, equally sensitive. There is, indeed, a spot, where the optic nerve enters the globe, completely insensitive to light. It is, therefore, called the "**blind spot.**" Light falling upon it produces no stimulus. At this point there are no rods and cones, and in this fact is one reason for the belief that the rods and cones are the agents by whose aid the waves of light become transformed into the stimulus of a sensation. A simple experiment proves this. Shut the left eye, and hold the thumbs of each hand side by side directly in front of the eye, with a good light falling upon them, and at the distance one would hold a newspaper in reading. Fix the right eye on the nail of the *left* thumb, and then move the *right* slowly away to the side. Though the eye is steadily regarding the left thumb both are seen, when the right is moved only an inch or so, but when the right thumb has been moved off several inches, the end joint disappears from view, though the shut hand is still visible, and when it has been moved a little further the whole right thumb is again visible to the eye, still fixed on the left thumb. The explanation is that at a particular distance the rays of light from the end of the thumb fall on the blind spot, and give rise to no sensation, and when the hand is moved to one side or other of this place the rays fall on the retina on one side or other of the optic nerve entrance and so produce the sensation. If when the thumb has disappeared the head be moved in any direction, backwards or forwards, the thumb will again come into view, for the rays will be made to fall on the retina. The same thing may be shown in another way. Shut the left eye and fix the right on the small letter a (fig. 105). Then move the book near to or farther from the eye. In one position the large letter A disappears from view, in others both are visible.

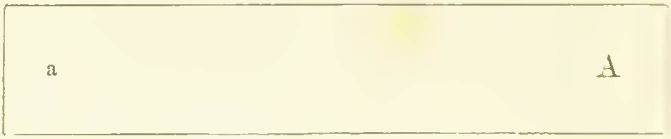


Fig. 105.—To show the "blind spot."

The yellow spot (p. 314), directly in the centre of the back of the eye, is the most sensitive part of the retina to light. Objects are most distinctly seen when the eyes are so directed towards them that light from them falls on the yellow spot. In this spot cones are specially numerous, there are no fibres of the optic nerve, and the other layers of the retina are very thin. This is another reason for the belief that the rods and cones are the true essentials of the terminal organ of vision. In looking at any extended object the eyes are rapidly moved in various directions, so that its various parts are brought in line with the yellow spot. As a result of a fusion of all the different impressions received, which fusion is effected in the brain, the person judges of the appearance of the object as a whole. This grouping of impressions we are often unconscious of. It is done so rapidly and so habitually that we are apt to believe that we see with equal distinctness the whole of an extended object at once. In reading a printed page we know the eye moves so as to perceive one word after another in the printed line, and if we fix the eye on the centre of the line the ends will be indistinct. It is because we move the eyes so rapidly, and because we learn to take notice only of the distinct impressions, due to rays of light falling on the yellow spot, that we are quite unconscious of the existence of a blind spot.

The stimulation of the retina does not pass off immediately the cause ceases to operate. Its effect lasts for a distinct period, about the $\frac{1}{8}$th of a second. If, therefore, two impressions follow one another at a less interval they appear as continuous, since the effect of the one has not passed off before the other is produced. If, in a series of flashes, one follows another at less than the interval named, the impression of a continuous flash will be produced. It is thus that a string, glowing red-hot at one end, and rapidly whirled round, produces the impression of a circle of light. This fact is taken advantage of in the construction of the wheel of life. Here a set of pictures is produced on a circular band of paper, which is set in a revolving wheel. The pictures represent a man, let us say, in the different positions he would be in, one instant after another, during the act of walking, for example. One picture follows another in its proper order, and when the wheel is rapidly revolved the appearance of the man walking is produced.

The Perception of Objects.—Were the retina the complete terminal apparatus of vision all that one could be conscious of would be a sensation of light whenever the retina was stimulated, but we could have no definite knowledge of the object from which the light proceeded. Photographers obtain a picture of a person by the use of a plate of glass on which is a film sensitive to light. This sensitive plate is placed in a box or camera, facing the person. But were the camera a simple box with a hole in front through which the light could fall on the plate behind, the result would be a uniform darkening of the film from the exposure to light and no picture would be produced. What the photographer desires is to throw on the plate an image of the person in light and shade. The parts of the sensitive film on which the light portions of the image fall are strongly acted on, and the parts on which the shadows fall are feebly acted on, and more or less feebly as the shadows are slight or deep. The sensitive plate is thus unequally acted on, and when the photographer has submitted it to the action of certain chemical solutions the film is left thick and dark where the strong light fell, but thinner and more or less transparent in the places corresponding to the shadows. If then he holds his plate up to the light and looks through it he sees in light and shadow an image of the person who sat before the camera. But to obtain this there must be certain definite parts of the sensitive plate corresponding to certain parts of the person. Thus, if the light is shining strongly on one side of the person's face, the sensitive plate must receive the rays reflected from that part of the face, and these rays must not be diffused over the whole plate, but made to fall on a part of the plate corresponding accurately in outline and in proportionate size to the part from which they have proceeded. So it must be with the rest of the figure. On the plate there must be parts corresponding to the parts of the person to be photographed. It is the same in vision. If not merely a general impression of light is to be obtained, but a definite knowledge of things, then on the retina there must be distinct luminous impressions, distinct regions of light and shadow corresponding to the lights and shadows of the object from which rays of light are proceeding to the eye. In short, we cannot see in absolute darkness, we see only when light enters the eye, and we see definite things only when rays of light fall on them and are by them reflected into the eye. If all objects reflected light equally from their whole surface we could not see things defined from one another; and we would have simply a consciousness of a uniformly illuminated surface. Things have definite outlines, and forms, because light is unequally reflected from different parts of their surface, the illuminated object being mapped out by the shadow that surrounds it. It is only, then, when such illumination and shadow are accurately reproduced on a sensitive photographic plate that an image of a person or object is obtained, and only when accurately reproduced on the sensitive coat of the eye that we can see things distinctly. How then is this accurate reproduction of light and shadow obtained? Let us examine the photographer's apparatus, for in it is an accurate representation of the eye.

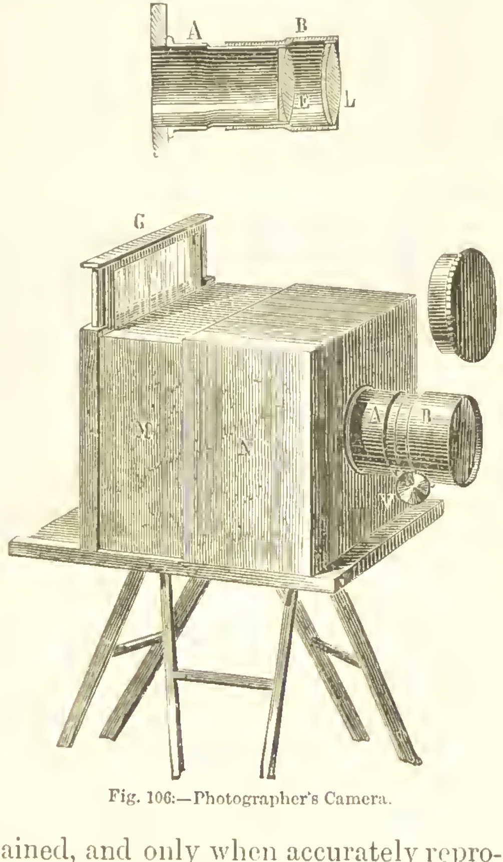


Fig. 106:—Photographer's Camera.

The photographic camera is a box (M N, fig. 106), the inner surface of which is painted a dull black, and which is light-tight. In front is an opening into which is screwed a brass tube (A B) fitted with a series of convex lenses, shown in the upper part of the figure (E L). A screw (V) enables the tube containing the lenses to be worked backwards or forwards in an outer case. The box is closed at the back by a ground-glass plate (G), capable of being removed. No light enters the box except through the opening in front (which may be closed by a cap), and it must pass through the lenses on its way.

The effect of a convex lens is exhibited in fig. 107. It brings rays of light passing through it to a point or focus (F) by refracting or bending them out of their course. Now suppose that the object from which the light is reflected is an arrow, as in fig. 108. The rays of light from the point of the arrow (A) are acted on by the lens and brought to a focus at *a*, the rays from the other end of the arrow are focussed by the lens at *b*, and rays from every other point of the candle are focussed at corresponding points between *a* and *b*, so that rays from every point of A B have corresponding points in the line *a b*. In short, an image of A B is produced at *a b* through the agency of the convex lens, but the image is upside down, because, as we see, *a* is the image of A, and *b* of B. Now if at *a b* a screen were placed, and if all light except that passing through the lens were prevented falling on

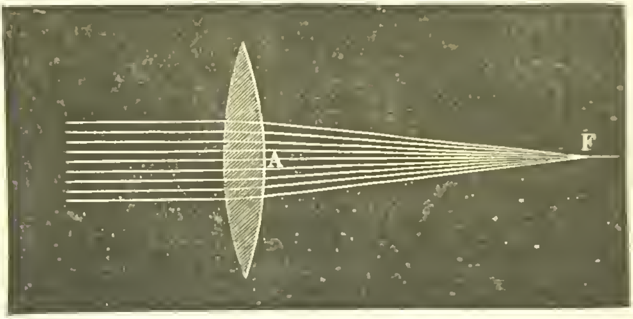


Fig. 107.—Effect of a Convex Lens.

the screen, a bright distinct image of the arrow would be seen, but smaller than the real object and upside down. The conditions would be accurately fulfilled if the screen were on the back wall of a black box which had an opening in front in which was fixed the lens. But this is just a camera with its ground-glass plate as screen. The inside of the box is blackened to prevent reflection of light which would mar the distinctness of the image. Now from fig. 108 it will be evident that if A B were brought nearer to the lens, its image *a b* would not be found in the same place. It would be further removed. The screen would require to be moved back a bit. Suppose

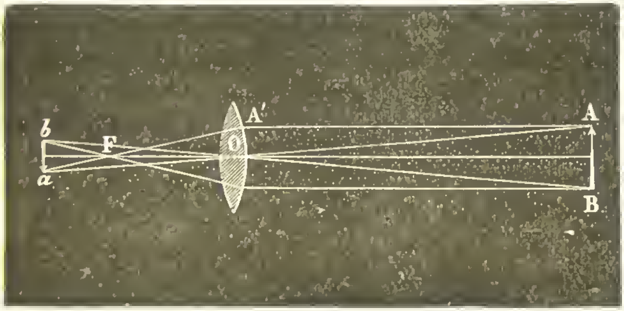


Fig. 108.—Formation of an Image by a Convex Lens.

the screen were immovable, the lens might be altered in position so as to bring the focus once more on to the screen. If the lens could not be moved, nor the screen, the new position of A B would cause its image to fall behind the screen. If another lens were placed in front or behind the original one its action would be strengthened, the rays would be brought to a focus sooner, and if the added lens had the proper degree of convexity (of thickness in the middle) the image would be brought forward so as to make it once more fall on the screen. Now in a photographer's camera the screw which moves the lenses backwards or forwards in their outer tube is for the purpose of bringing the focus always on the ground-glass plate. Usually also the box is made so that it can be lengthened or shortened to effect the same purpose, for the lenses always remain the same. Another thing remains to be noticed about the photographer's camera. Lenses focus more quickly rays of light passing through them near the circumference than those passing through the centre. Both sets of rays are not focussed at the same point. If the rays come from an object, the image produced is not definite, because all the rays of light are not equally focussed. Now in a camera this is corrected by the use of a stop or diaphragm. It consists of a plate of metal with a hole in the centre. This is passed through a slit in the metal tube between the lenses. It cuts off the outside rays, the centre ones only passing. The holes are made of various sizes to suit the amount of light. By means of the stop an element of confusion is removed and the image made very distinct.

Now if this description of a photographer's camera be applied to fig. 103 it will be evident how accurately it represents the purposes of the eyeball. The eyeball is a chamber with compact walls into which light can pass only through a clear portion in front (the cornea). Like the camera the eyeball has a dark coat to prevent reflection of light, the dark choroid. Towards the front is a lens—the crystalline lens—through which all rays of light that enter the eye must pass. The lens focusses the rays as any ordinary lens would do. But the action of the lens is aided. There are several refractive substances forming the eye. The cornea refracts slightly, so also does the aqueous humour filling the anterior chamber, and the vitreous humour filling the posterior chamber does so to a greater extent than either cornea or aqueous humour. Thus the moment rays of light enter the eye they begin to be bent out of their course, and the result of the action of the lens, aided by the cornea and aqueous and vitreous humours, is that rays of light that are parallel when they fall upon the eye are brought to a focus on the back wall. If then an object is a long distance off, rays of light proceeding from it and falling on the eye are brought to a focus on the back wall of the eye, and there will be produced a small image of the object *upside down* (fig. 109). Suppose the object is brought near, then, as we have seen with a lens, the image would fall beyond the wall of the eyeball. To secure that it fall on the wall exactly, one of three things is necessary, the wall must be moved further back, or the lens must be capable of movement, or there must be some way of increasing the focussing power of the lens, so that the rays are sooner brought to a focus, and thus made to fall on the wall. In the eye it is the convexity of the lens that is altered, and by this means the eye is capable of accommodating itself to different distances.

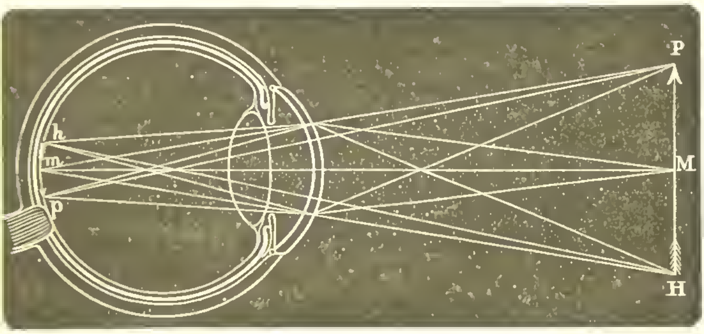


Fig. 109.—Formation of Image on the back of the Eyeball.

Rays of light proceed from the points P, M, H of the arrow and are focussed by the lens and humours of the eye to form an image, *p*, *m*, *h*, which is smaller than the object and inverted.

Accommodation of the Eye to different distances.—The lens is a very elastic body, and is confined within a capsule which presses upon it, and flattens it somewhat. But the pressure of the capsule may be relaxed by contraction of the ciliary muscle (p. 311), so that the lens bulges forwards and becomes more convex. When we look at a near object the ciliary muscle contracts, the capsule relaxes, the lens bulges forwards, the rays of light are thereby more refracted and the image of the object is distinctly produced on the back of the eyeball. When the object is nearer, the ciliary muscle contracts more, and the lens becomes still more convex. When the object is removed, the ciliary muscle relaxes, the capsule tightens, the lens is flattened slightly, refracts less strongly, and the image is formed on the back wall as before.

Normal or regular **Sight** exists when the degree of convexity of the lens and the length of the eye are such that rays of light coming from a distance are brought to a focus on the retina—the lining of the back of the eye—*without any effort of the eye*, the eye remaining at rest. Practically all objects at a distance of about 70 yards and upwards from the eye require no effort of accommodation. This distance from the eye is the far point at which the need of accommodation ceases, and it has been called the *punctum remotum*, or far point. As soon as an object comes nearer than this, the lens must begin to become more convex, and the nearer the object comes the more does the lens increase in convexity by the contraction of the ciliary muscle, till the object is so near that every effort is made to produce greater contraction and thereby greater convexity, and a sense of straining is experienced. A point is at last reached so near to the eye that no further accommodation can be effected, and, if the object is brought nearer, it is no longer distinctly seen. This point is the *punctum proximum* or near point, and for the ordinary eye the distance is about six inches.[1]

Long-sight (*Hypermetropia*).—If the arrangements necessary to secure distinct vision when a person looks at objects at varying distances from the eye be under-

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[1] **Scheiner's Experiment** illustrates the need of accommodation. Pierce with a needle two small holes close to one another in a card. Hold the card in front of *one* eye, and hold the needle up in front of the card, viewing it through the holes. Move the needle nearer to and then farther from the eye. At one point the needle will be distinctly seen, in other positions it will appear blurred, and even double. A kind of double vision with one eye will be produced. Fig. 110 supplies the explanation. A and B are the holes in the card, *a* the needle point, C a lens, and D, E, F a screen at different distances from *a*. The rays from *a* passing through A and B unite at *o*, and with the screen in this position a single image of *a* is produced. If the screen be at F, the rays *m n* are not united and a double image is produced, and so also if the screen is at D. Similarly, a single or double image is produced on the retina of the eyeball by varying the position of the needle as described.

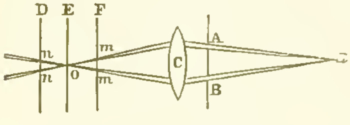


Fig. 110.—Scheiner's Experiment.

stood, the defects of the eye, termed long-sight and short-sight, will be readily comprehended. We have seen that, in ordinary conditions of the eye, rays of light from distant objects form a picture on the retina without any effort on the part of the eye. Now suppose the distance between the back wall of the eye and the front is less than usual, rays of light from far-off bodies will reach their focus, not on the retina, but behind it, because the retina is not so far back as it ought to be. (Refer to fig. 111.) If the difference from the normal be slight, the person is able to correct it by a slight effort of accommodation. By this slight effort the lens becomes more convex, brings the rays sooner to a focus, and thus brings the picture forwards so as to make it fall on the retina. The effort required may be so slight that for a long time the person is unaware of it. But the meaning of the condition is, that even when the person is looking at far-distant things, which in ordinary circumstances he should see distinctly without any movement of the lens, his eyes are not at rest, but require to focus to make the image fall on the retina. As the object comes nearer the amount of focussing required becomes greater, and the power of accommodating the eye to see distant objects, having begun sooner than is usual, is sooner exhausted. That is, the eye becomes unable to focus any further before the object has come so near the eye as is usual. Thus a person with long-sight is unable to read a letter or newspaper, let us say, when it is held the ordinary distance from the eye, because his focussing power has failed sooner than is customary. He, therefore, holds the paper or letter farther off from his eye than ordinarily is done. The "near point" is farther away from the eye than in ordinary sight. The defect is called "long-sight" on this account. The remedy is evident. By placing in front of the eye a spectacle whose surface is convex—rounded—the lens is aided, the focus of the rays is brought forward, and the person can now hold his letter or paper nearer and yet see distinctly.

Short-sight (*Myopia*) is the opposite condition to the former. The distance between the back and front of the eye is greater than usual. When the person looks at distant objects, the focus does not fall on the retina as in ordinary sight, nor yet behind the retina as in long-sight, where the distance is less than usual, but it falls in front of the retina. (Fig. 111, C.) It is plain that the person can do nothing to correct this. His eyes are at rest, and yet the focus is in front of the retina. Any effort of accommodation would make things worse, by making the lens more convex, and bringing the image still farther forwards. If the lens could be flattened so that the rays were not brought to a focus so soon, distinct vision would result, but there are no arrangements for doing this. The eyes are at rest, and in this state the lens has its least degree of forward curve. Now as the object looked at comes nearer and nearer the focus gradually passes back till at length it falls on the retina, and the person then sees the object distinctly. Thus a short-sighted person cannot see persons or things distinctly *at a distance.* Moreover, a short-sighted person sees distinctly, and without any accommodation by his eyes, that is, his eyes being at rest, an object at the distance for which a person with ordinary sight requires to focus strongly. That is to say, the short-sighted person does not require to bring into play the arrangements for accom-

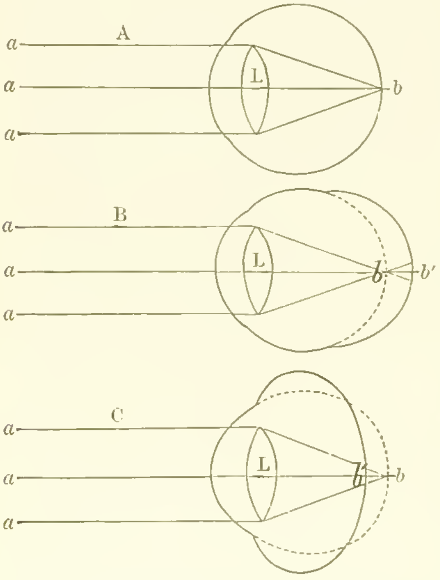


Fig. 111.—A, Ordinary Eye, rays of light *a a* from a distance coming through the lens L to a point *b* on the retina. B, Short-sighted Eye, rays from a distance coming to a point *b in front* of the retina *b′*. C, Long-sighted Eye, rays from a distance coming to a point *b behind* the retina *b′*. L is the lens in each case.

modation so soon as the person with ordinary sight, and thus the accommodation of the person with ordinary sight is exhausted before that of the short-sighted person. Thus, when the ordinary individual has brought printed matter so near his eyes that if he holds it any nearer it is no longer distinct, the short-sighted person can bring it much nearer and still see it distinctly. Indeed to see it distinctly he requires to hold it nearer than the ordinary reading distance. On this account the defect is called "short-sight." To correct this some arrangement is required which will prevent the rays of light coming so soon to a focus, by which means the image will be produced farther back and made to fall on the retina. A concave spectacle—one hollow on the surface—does this, for it slightly disperses the rays, and they are brought to a point later than they would otherwise be.

The Movements of the Eyeball.—The eyeball is controlled by a set of six small muscles, which, with one exception, are attached to the back part of the cavity in which the eye rests. The muscles pass forwards and are connected by thin flat tendons to the outer coat of the ball, a short distance behind the clear part of the eye—the cornea. Four of these muscles run a straight course, and are called **recti muscles** (Latin *rectus*, straight). One is attached in the middle line above, another below, and one to each side of the eyeball. They are, therefore, called superior, inferior, internal and external. Acting alone one would turn the eye upwards, another downwards, the third inwards, the last outwards. The other two muscles bend in their course, and are called **oblique muscles**. One arises behind in common with the four straight muscles, and passes to the front towards the inner angle of the socket, there it ends in a round tendon and passes over a tendinous pulley. From the pulley it changes its course, proceeds over the eyeball slightly backwards and becomes attached to the ball at its outer side. When it contracts, acting round the pulley, it rolls the ball. Since it proceeds over the eye it is called the **superior oblique muscle**. The other oblique muscle is below—**inferior oblique.** It springs from the lower part of the inner angle of the socket and passes below the ball towards its outer side where it is attached. When it contracts it also rolls the eyeball, but in an opposite direction to the superior oblique. These oblique muscles do not act alone, but in association with one or other of the straight muscles. In combination they produce the varied movements which the eyeball can so freely perform.

As a rule both eyes are moved at the same time in the same direction, so as to regard the same object. When one muscle becomes paralysed so that the eyeball cannot be turned in that direction, the two eyes no longer act together, when the person seeks to look that way. The sound eye is turned far enough, the other fails to go round. Squinting is produced, and the particular object looked at is seen double. As soon as the eyes are turned in other directions, they again act together, the squint disappears and the vision is single. (Refer to **Double Vision**, p. 333.)

The information gained by the Eyes.—It may be well to state here briefly the substance of the foregoing paragraphs. The eye is to be regarded as the peculiar form of ending of the optic nerve, designed to be affected only by light, and so excited by light as to send on to the brain an impression which there gives rise to a sensation of light. It is supplied with a series of structures that act as convex lenses, which so focus rays of light, passing through them from external objects, as to form small images of these objects on the retina, the nervous coat that lines the inner surface of the back chamber of the eyeball. Now the first thing to notice is, that it is this image on the retina that produces the sensation of seeing something, and yet we are not conscious of the image on the retina but only of the outward thing from which the rays of light proceed. This is difficult to understand. It is doubtless the result of education. We learn that the things we see are the result of impressions reaching us from the outside, and we refer the object, from which the impressions reach us, outwards in the direction of the straight lines in which the rays of light fall upon the eye. Thus, it is related of a patient, who was blind from his birth owing to cataract, that when sight was restored by an operation, performed by the English surgeon Cheselden, he thought all objects he saw touched his eyes. His other senses corrected his mistake. He found when he put his hand up that the objects did not touch his eyes, that he had to walk towards them in order to touch them, &c. Thus he trained his eyes by means of other senses, and in other ways, to appreciate the distance from him of the objects he saw. Again, when pressure is exerted on the eyeball, or when a sudden blow is received on the eyes, the nervous apparatus of vision is excited and colours or bright sparks (called **phosphenes**) are seen, which only experience teaches to be due to internal disturbances. The production of what are called **Purkinje's figures** is another example of the same thing. If a person goes into a dark room with a lighted candle, and, facing a blank plain-coloured wall, holds the candle to the side of the head, moving it up and down, the appearance of branching lines will be seen on the wall. These are shadows of the blood-vessels of the retina (p. 313). The sensitive portion of the retina (the layer of rods and cones) is behind the blood-vessel layer, and thus the lines of vessels intercept the light passing in at the extreme side of the eye, the shadows produced appearing to the person to be something outside. Then it is well known that minute floating bodies in the humours of the eye produce shadows which seem to the person to float across his vision in space. These are called **muscæ volitantes**. It is, then, only by a process of education, in which the various senses take part, that a person learns to judge of the actual existence of an outward object corresponding to his sensation. It may be remarked that a similar explanation applies to **hallucinations**. This is the term given to things a person seems to see for which there is nothing externally to account. There are undoubted cases on record where an individual has seen a person or thing in the immediate neighbourhood, and by going up to the place has assured himself that nothing but simply space existed there. Sir David Brewster gives a case, in his *Natural Magic*, of a lady who on entering the drawing-room saw her husband standing on the hearth-rug with his back to the fire. She addressed him and sat down in a chair within two feet of the figure. After she had again spoken, the figure moved off to the window and then disappeared. Frequently afterwards she had similar experiences. In these cases changes were excited in the nervous apparatus of vision not due to any outward existence, though as a rule only produced by such, and the lady was consequently for the time deceived, until she had corrected her sensations by other means.

Another thing to be noticed is that the image on the retina is upside down, and yet we see things in their upright position. When we direct our eyes towards a particular object rays of light pass into the eye not only from that object but from other parts in its immediate surrounding, and we become conscious not only of the particular object we are looking at but of a region round about it. This region is called the **visual field** or **field of vision.** Now rays of light coming from the left of the field of vision fall on the right side of the retina, rays from the upper part of the field fall on the lower part of the retina, rays from the lower part of the field on the upper part of the retina, and so on. We refer the image on the lower part of the retina in the direction from which the rays come, that is, towards the upper part of the field of vision. Moreover we interpret by means of touch, for, to reach with the hand the part of the object whose image is on the lower part of the retina, we must raise the hand, and to touch the part of the object whose image falls on the right side of the retina we must pass the hand to the left side, and so on. Thus though the image is upside down on the retina, we see the object upright.

The **estimate of size** given by the eyes depends on the angle formed by the rays of light before crossing in the eye. This is explained by fig. 112. From the object

P A H, rays P *p*, H *h* pass to the eye. At O they form an angle P O H. This is the visual angle, the angle under which P A H is seen. P A H forms an image *p h* on the retina, and its apparent size is dependent upon the angle at O. But the lines P′B H′ and P″C H″ are seen under the same visual angle, and will, therefore, have the same apparent size, and form images of the same size on the retina. To this impression, however, there remains to be added the idea of distance. We know that as objects pass farther and farther away from us they appear smaller and smaller, and as they approach they become larger. If, therefore, an object at a great distance off appears as large as an object very near to us, we judge the far-off object to be much more extensive than the near one.

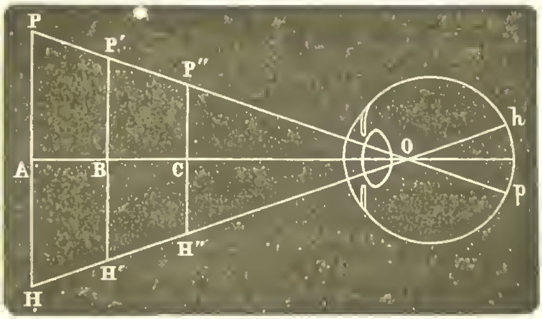


Fig. 112.—The Visual Angle.

Our **appreciation of distance** is guided to a large extent by the clearness with which the object looked at is perceived and its details made out. If the atmosphere be very clear, mountains at a distance appear nearer than they do when the atmosphere is hazy. An artist gives an impression of distance to the objects in the background of his picture by the want of distinctness of their outline and detail. It is very difficult, however, to judge absolutely of distance. Between us and a distant object a great many other objects intervene, whose distance from us we can more readily estimate. We thus guide ourselves in forming an idea of the distance of the far-off object by the others which are between, and which afford us something to measure by. Thus everyone knows the errors easily made by sailors at sea in judging of the distance between their ship and another, because of the absence of anything between to aid the vision.

For various reasons, therefore, judgments formed by vision of the real size and distance of things are not too reliable. A good illustration is given in fig. 113. The distance between A and B seems greater than the distance between B and C, and yet it is the same, the apparently increased space between A and B being due to the markings between. For the same reason, of two squares absolutely identical in size, one marked with alternately clear and dark cross-bands, and the other with alternately clear and dark upright markings, the former will appear broader and the latter higher than the other. Thus a short stout person whose dress is cross-striped or made with flounces appears stouter than she really is, and a tall woman whose dress has upright markings or folds that run up and down exaggerates her length. Consequently a stout person who wants to increase her apparent height and diminish her apparent stoutness should wear dresses striped or folded up and down, and a tall person who wishes to diminish her apparent tallness and to appear stouter should wear cross-marked or folded dresses. Thus most sensations are really of a very complex description. When we look at an object and say it is round we are not expressing the result of a simple sensation. The visual impression is that of a particular relationship of light and shade. We recall the experience of similar impressions, and associate probably tactile sensations formerly felt, and the ideas we acquired from them. All this enters into the formation of our judgment.

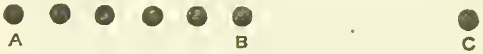


Fig. 113.—Judgment of Distance.

Single Vision with Two Eyes.—When we look at an object with both eyes, it appears under ordinary circumstances as a single object. Two images of the object are produced, however, one on the sensitive coat (retina) of each eye, though we are not conscious of two images. If now a finger be pressed strongly on one eyeball so as slightly to push it to one side, the object will appear double; when the pressure is removed the object is again single. It seems, therefore, that single vision with two eyes is produced when the image of an object falls on the corresponding part of each retina. If one eye be so displaced that the image falls on a part of its retina that does not correspond to that of the other eye, then the object appears double—**double vision**, as it is called, is produced. In looking from one object to another the eyes are moved together in harmony with one another, and single vision is constantly secured. If, however, a person suffers from paralysis of one of the muscles of one eyeball, then it is evident that when the eyeballs are moved in a particular direction the paralysed muscle will be unable to contract, will be unable to pull the eyeball round in that special direction, and thus while the eyeball, whose muscles are all sound, is properly directed to the object, the other one cannot be sufficiently brought round, the image of the object will not fall on corresponding points of the two eyeballs, and double vision will result. Since only one muscle is affected, the eyeball can be moved quite freely in every direction but one, and thus in all other directions single vision will be produced, because in all directions but one both eyeballs will act together. Persons who squint would also "see double" were it not that they accustom themselves to use only the straight eye, and speedily become altogether unconscious of the image on the squinting eye.

Binocular vision, that is single vision with two eyes, enables us to judge of the solidity of objects looked at. The image that falls on each eye is not absolutely the same, because each eye regards the object from a very slightly different point of view. The two images, differing so little from one another, are fused together in our consciousness; but the result of the slight difference is to give us a particular impression which experience has taught us is due to the object being not flat but raised —we have, that is, the impression of a solid body. This may be illustrated by a very simple experiment. Fig. 114 shows two views of a cube; the view on the right hand presents the appearance that would be perceived suppose a cube were looked at by the right eye, while on the left hand is the appearance of the cube to the left eye. the position of the person not being changed. Now let one take a card about 10 inches long and hold it between the two views, let the person rest his forehead on the upper end of the card and look on the figure. so that the left eye sees only the left view and the right eye sees only the right view; with a slight converging of the eyes only one cube is seen, but it is neither the right-hand nor left-hand view, but a view produced by an overlapping of the two, and the cube stands out from the paper as if it were actually a solid body.

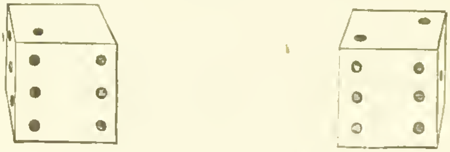


Fig. 114.—Stereoscopic Views.

This is the principle of the **stereoscope,** fig. 115. It is a box divided into two sides by a thin partition down the centre. In the bottom of the box is placed a card on which are pasted two photographs of the same thing. Each photograph, however, has been taken from a slightly different point of view, so slightly different that, without careful examination, one would conclude they were both absolutely the same photographs. The views are of such a size that each one extends across the space in the bottom of its compartment. and the central partition

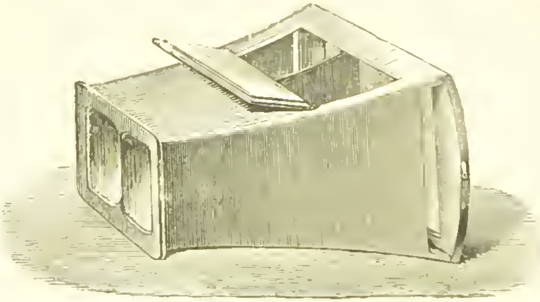


Fig. 115.—The Stereoscope.

accurately separates the two. At the opposite end of the box are two lenses, so placed that when the box is held up to the eyes each eye looks through one lens. Looking through the glasses each eye sees a photograph, slightly magnified. The lenses are of such a shape that they cause a slight displacement of the pictures, so that the images fall on corresponding points of the two eyes. The two images are fused together, and one becomes conscious of only one picture, in which the objects stand out in relief, just as they would appear were one looking at the actual objects themselves. In the **pseudoscope** the lenses are so arranged as to transpose the images. The reliefs are reversed, so that, for example, the head on a coin which usually appears standing out seems to be hollowed out of the coin.

Colour.

Ordinary sunlight is found to be compounded of seven different colours: red, orange, yellow, green, blue, indigo, and violet. If a wedge-shaped piece of crystal—a prism—be held up between the sunlight and the eye, these various colours will be seen, because the prism separates the white light into its constituent colours. The band of the different colours produced in this way is called a spectrum—the spectrum of sunlight. The rainbow is such a spectrum. The compound nature of white light can be shown in another way. If the seven colours be painted on a wheel as indicated on fig. 116, and in proper proportion,

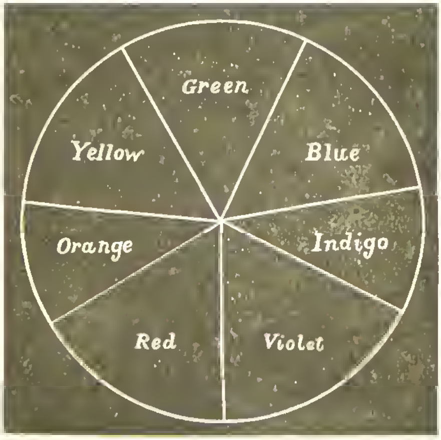


Fig. 116.—Rotating Disc of Sir Isaac Newton for mixing Colours.

and the wheel be turned on a pivot through its centre with great rapidity, the eye will not perceive any colour at all, but the wheel will appear a dull white. If, however, one of the seven colours be omitted, the revolving wheel will be no longer white. The six remaining colours will still be fused together, so as to give the impression of one colour—the result of the union of the six.

Now bodies appear variously coloured because of their behaviour to white light. Some bodies held up between the light and the eye permit all the rays to pass through, and therefore appear without colour, other bodies do not permit all the rays to pass, they intercept some. Thus one body keeps back all rays but the red; they alone pass through, and thus the object appears red. Another body keeps back all the rays but the yellow and some of the red, and it appears to be orange. A third body permits only the violet rays of white light to pass. and it, therefore, appears violet, and so on. Again another class of bodies do not permit rays to pass through them, but they reflect rays. Their apparent colour depends upon whether they reflect white light unchanged, or whether they reflect only some of the seven different rays of white light and retain or absorb others. A body that reflects the white light unchanged appears white, a body that does not reflect it at all, but absorbs it, appears black. One body absorbs all rays of white light except red, these it reflects; and it appears red in consequence. If a beam of red light be thrown on such a body, say a piece of red ribbon, it reflects the rays and appears brilliantly red. But let a ray of yellow light be thrown on the red ribbon, it does not reflect but absorbs yellow light; in consequence it appears no longer bright coloured, but almost black. An orange ribbon reflects partly red and partly yellow rays of white light. the others it retains. and it therefore appears orange, that is a blend of red and yellow.

It has been said that the seven different colours of the spectrum, painted in certain proportions on a wheel which is turned with great rapidity, will produce the impression of white. It has been found that these seven separate colours are not required, but that the impression of white can be produced by three colours only, viz.:

Red.
Green.
Violet.

These three painted in proper proportion on a wheel will give the impression of white. Moreover, all the seven colours of the rainbow can be produced by varying the proportion of these three colours. On this account they are called the **fundamental colours.**

Complementary Colours are not to be confounded with the fundamental. There are certain pairs of colours which when blended produce a sensation of white. Thus:—

Red	and	Blue-Green	produce	White.
Orange	,,	Blue	,,	,,
Yellow	,,	Indigo-Blue	,,	,,
Green-Yellow	,,	Violet	,,	,,
Green	,,	Purple	,,	,,

That is to say, given red, the other colour required to produce white is bluish-green; or given bluish-green, the other colour required is red, and so on. These colours are therefore said to be "complementary" to each other, because they together produce white.

Here a mistake must be guarded against. It must not be supposed that it is meant that a mixture of paints of these colours will produce a white paint. A red powder and a bluish-green powder will not produce a white one, as everyone knows, nor the mixture of red and bluish-green liquids. But if, at the same instant, the eye be affected by red and bluish-green light, the sensation is not of either colour, but of white. It is the sensation that must be mixed, so to speak, and the mixed sensation is not produced by a mixture of the differently coloured powders or liquids.

The Perception of Colour by the eye is explained by a theory first proposed by Thomas Young, and afterwards more fully worked out by the German professor, Helmholtz. According to that theory there are in the eye three sets of nerve-fibres capable of being excited by the fundamental colours (see above). One set is excited by red light, another by green, and another by violet. Just as the different colours of the rainbow may be produced by various proportions of these three colours, so may different sensations of colour be produced by the excitement of these three sets of nerve-fibres in different amounts. Thus, when all the three sets of fibres are nearly equally excited, there is a sensation of white. Red light will strongly arouse the nerve-fibres sensitive to red, and will barely affect the other two. Yellow light will moderately excite the fibres sensitive to red and green, and not those sensitive to violet, and the result is not a sensation of red or green, but of yellow. Blue light excites moderately the fibres sensitive to green and violet, and barely affects those sensitive to red, and there is a sensation of blue. This theory would account for colour-blindness. Thus, if the fibres that ought to be sensitive to red, for some reason or other did not respond at all, the person would be unable to perceive red.

After-images are also explained by the theory of colour and its relation to the perception of colour. If, on awaking in the morning, we look *for an instant* towards a window through which bright sunlight is streaming, and then turn away the head and shut the eyes, we are aware of an image of the window, in which the panes appear white and the sashes, &c., dark, as they appeared when actually looking at them. This is a **positive after-image**, and is due to the fact that, the sensitive coat of the eye being highly excitable by the long rest of the night, the effect of the stimulus of the light lasts for a considerable time after the exciting cause has ceased to operate. If, however, we gaze *for a time* at the window and then look away and shut the eyes, or look towards a dark part of the room, we see an image in which the light and dark parts are reversed, the panes being dark and the sashes white. This is a **negative after-image**. It is due to the sensitive coat of the eye being fatigued in certain parts. The parts corresponding to the panes, on which the strong light fell, are exhausted and appear dark, while the parts corresponding to the sashes, on which the light did not fall, are still unexhausted and therefore appear light. In a short time the retina recovers and the experiment may be repeated.

Now, suppose we look fixedly for a short time at a white sheet of paper on which is a red spot, a bright light falling on the paper, and then turn the eyes to a plain white sheet of paper or to a white wall, an image of the spot will appear to float before the eyes, but it will not be a red image but bluish-green. The explanation of this is similar to that of after-images. The sensitive coat of the eye has been exhausted, but not to all the constituents of white light, only to the red. The result is that an after-image floats before the eyes, whose colour is that of white light less the red, in other words, the colour which with red goes to make up the sensation of white, the complementary colour of red, namely bluish-green. Similarly if the spot gazed at has been bluish-green, the after-image will be red. If the spot be orange the after-image will be blue, &c. The experiment may also be varied. Thus a large red spot may have a name written across it in another colour, in which case the after-image would show a bluish-green ground and the name would be in a different complementary colour.

HEARING.

The Nature of Sound.

Sound is a form of movement. This may be shown in various ways. We all know that a tightened string may be caused to give out a musical sound by being pulled strongly to one side and then let go. The string makes a rapid to-and-fro motion, which is accompanied by the sound. As the motion becomes less vigorous the sound becomes feebler, and when the movement stops the sound also ceases. The limbs of a tuning-fork are in rapid motion when it is sounded. In the case of very large heavy forks the to-and-fro movement can be seen; but in the case of small forks, such as those used by musicians, the motion is so fine and rapid that it is not visible. When a bell sounds, after being struck, it can be shown to be in motion, not moving as a whole, but the particles of which its mass consists being in rapid vibration. Now suppose we have a small bell, the hammer of which is worked by clock-work; let us place it on the plate of an air-pump, resting on a thick cushion of felt; and let it be covered with the glass bell-jar of the air-pump. If the clock-work be working we still hear the sound through the glass. Now let the pump be worked so as to remove the air from the chamber, and as soon as a considerable quantity of air has been removed the sound becomes very feeble. When the glass jar has been as completely exhausted of air as possible, the sound is no longer heard, though the hammer may still be seen to strike the bell. The stroke still causes vibrations of the particles forming the substance of the bell. but owing to the absence of air there are no means of communicating the vibrations to the ear of anyone in the neighbourhood. This shows, then, that sound is a movement, that it is only when the movement is conveyed to the ear and affects the nerves of hearing that the sensation of sound is produced, and that it is usually the air that is the medium by which the motion is transmitted to the ears.

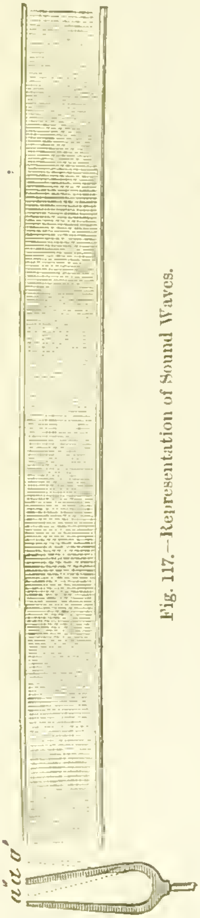


Fig. 117.—Representation of Sound Waves.

The sound movements, or vibrations, as it is better to call them, are conveyed through the air in a wave-like fashion, represented in fig. 117. The figure shows a tuning-fork supposed to be sounding. Its limbs are, therefore, in a state of rapid vibration. In the figure what occurs is shown only on one side. The limb *a* moves to and fro, now in the position *a′*, and now in position *a″*. When the limb moves from *a* to *a′* the air in contact with it receives a shock, and the particles of the air are crowded together by the blow. When the limb moves from *a′* to *a″* the particles that were crowded together have now more space at their disposal, and are less crowded than before the shock of the limb. But with great speed the limb moves back from *a″* to *a′*, and again the particles are crowded, and then it rapidly returns to *a″*, when the greater space is again created. Thus, while the fork continues to vibrate, the particles of air in its immediate neighbourhood are at one moment crowded together, at another moment the opposite is the case, and this goes on on each side of the fork as long as its movements continue. The crowding together of the particles of air by the shock of the fork is called a *condensation*, and the opposite movement a *rarefaction*. To use these terms, then, the air on each side of the limb of the fork is at one moment in a state of condensation and at another moment in a state of rarefaction, in time with the vibrations of the fork. But this peculiar agitation is not confined to the air that is in immediate contact with the fork. The condensation travels outwards from the fork through the atmosphere, and the rarefaction likewise; and as long as the fork keeps going these two conditions are passed along through the atmosphere from the sounding body, which thus becomes a centre of disturbance, just as a stone thrown into still water imparts a shock to the water, and from the place where it struck waves pass outward on all sides. Fig. 117 represents by the difference in the shading the alternate condensation and rarefaction. Now we all know that a person in a boat on the water will become aware of the agitation of the water, even though at a distance from the centre of disturbance, by the waves rippling up to him. Even so a person becomes conscious of a disturbance in the atmosphere, though he be at a distance from the place where it is produced, because the waves of condensation and rarefaction, spreading outwards on all sides from the vibrating body, at length reach him and beat upon him. They affect his ears, they irritate his nerves of hearing, and so he becomes aware of what he calls sound. If we could see air as we see water, we would perceive the disturbance, caused by a sounding body, passing through it.

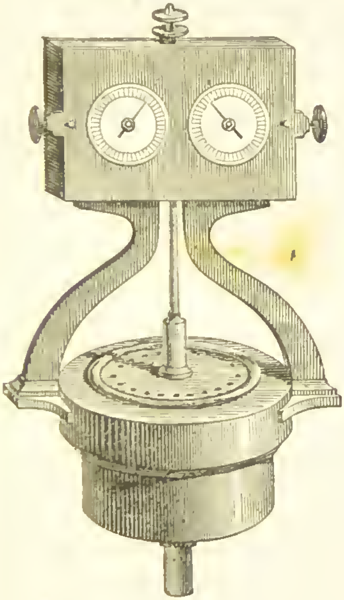
It takes a certain time for sound to travel. The rate is about 1090 feet per second when the temperature of the air is 0° Centigrade, and is increased when the temperature is raised. Everyone who has watched from a distance the discharge of artillery knows that the flash and smoke from the gun's mouth are perceived a brief time before the report is heard. If the interval between the two be taken, remembering the rate at which sound travels, one may readily make a rough estimate of the distance of the gun—allowance, of course, being made for wind. Now if the atmosphere were visible, with the gun's discharge, a tremendous disturbance would have been seen to take place in the air at the gun's mouth at the moment the flash was seen. This disturbance would be seen spreading outward in all directions and travelling with great rapidity. Suppose the person stood watching the advancing agitation, then, just at the moment when it reached and enveloped him, he would hear the report. So that when a person walks through a crowded and noisy thoroughfare, his ear is being assailed by numberless waves of sound of all kinds and sizes and degrees of rapidity, that surge and swell in the atmosphere around him.

There are various characters of sounds which it is necessary to have some idea of for the proper understanding of the apparatus of hearing. These characters are best exemplified by musical sounds, which are distinguished from ordinary sounds by the regular rhythmical character of their wave movements.

Musical Sounds differ in loudness or intensity, in pitch, and in kind or quality.

The **loudness** of sounds depends on the extent of the vibration or movement—the largeness of the wave, so to speak.

The **pitch** of the sound is determined by the number of vibrations that take place in a second of time. Thus a tuning-fork whose limbs move to and fro 100 times a second will give out a sound of a certain pitch, and a tuning-fork that executes 200 movements in the same time will sound a note of a higher pitch—will, in fact, sound the octave of the former fork. This is shown in a very beautiful way by an instrument devised by a Frenchman, Cagniard de Latour, and called a **siren**. It is shown in figs. 118, 119. It consists of a metal box, the floor of which is pierced by a tube, placed in connection with a large bellows. In the roof of the box is a small round opening, passing in a sloping direction. Fig. 119 shows



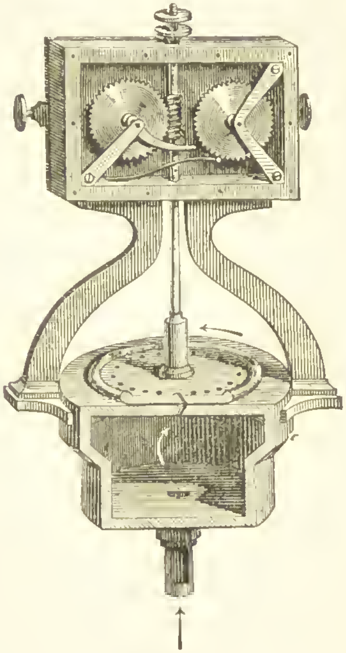


Fig. 118. The Siren. Fig. 119.

a piece cut off the box so as to exhibit this opening. Above the fixed roof of the box, but very close to it, is a round plate, with a number of openings pierced in it, which slope in an opposite direction to that of the roof. This plate turns on a fine pivot, so that one hole after another can be brought opposite the opening in the roof. Fig. 119 shows one hole in the plate opposite the opening in the roof of the box, and the different slope of the two openings is seen. Fig. 118 shows the siren complete. Now if air be driven from a bellows into the box, it escapes by the opening in the roof; and as it rushes out it strikes against the edge of the hole in the plate, and the "puff" of the escaping air is heard. The plate, being easily moved, is by this means made to turn, and so the opening in the roof becomes blocked; but when the plate turns a little farther a second hole in it comes opposite the opening in the roof, the air again rushes out, produces another "puff," and drives the plate round a little farther. Again the opening is blocked, and with the continued turning of the plate it is again speedily opened. If the bellows be worked hard the plate will be driven round fast, and the opening in the roof will be opened and closed very rapidly. Every time it is opened a shock will be given to the atmosphere by the escaping puff of air. Fixed to the apparatus are two dials which mark the number of turns made by the revolving plate. If one knows how often the plate turns in a minute, and the number of holes in the plate, it is easy calculating how many shocks the air will receive in a minute. Now it is found that if the bellows be worked so feebly that the plate turns so slowly as not to open and close the hole in the roof sixteen times a second, the puffing sound is heard each time the air escapes. But if the hole in the roof of the box is opened and closed sixteen times a second, which would be effected if the plate were turning once a second, and if it were pierced with sixteen holes, then the sixteen puffs are not heard as separate sounds, but are blended together and a low musical sound is heard. If the bellows be worked more and more quickly the plate turns faster and faster, the number of shocks given to the air in a second of time is increased, and the sound is heard to rise in pitch, until with the utmost speed of the plate it becomes a high shrill sound. The instrument shows conclusively how pitch of sound depends on the number of vibrations produced by the sounding body in a second of time.

Quality, kind, or **character** of musical sounds depends on something very different from loudness and pitch. We speak of a sound being harsh, or mellow, or rich, &c. We know that a note of the same pitch, sounded on a piano, a trumpet, and a violin, differ very markedly in quality, and that a note of the same pitch produced by the human voice differs from them all. Each instrument, that is to say, has a quality of its own. If a tuning-fork of the same pitch be sounded, we are aware of a great difference. The sound might be called thin, or poor, wanting in quality. It is, indeed, so wanting, for a tuning-fork produces what is called a pure sound. But suppose the tuning-fork vibrates 100 times per second, and that we take another vibrating 200 times a second; it will produce a sound the octave of the first. Let us take a third, vibrating 300 times, the octave of the second, a fourth, vibrating 400 times, and so on up to an eighth, vibrating 800 times per second; then we have a set of forks all related to the first, in that they vibrate twice, thrice, four times, &c., as often as the first. If, beginning with the first, they are all sounded one after the other, we perceive the sound of each one immediately after it is produced, but the different sounds immediately begin to blend. When all are sounding we are not aware of eight different sounds, but of one sound of a definite pitch and peculiar quality. The pitch is given by the note of the one with which we began, which is called the **fundamental note,** and the particular quality is due to the blending of the other notes, which are called **over-tones** or **harmonics.** The quality may be altered by causing only some of the forks to sound along with the first one; and it is mellow if the forks with fewer vibrations sound, while it is ringing if those with most vibrations are set going. The quality of the sound produced by a violin string is due, therefore, to its vibrating not only to produce the fundamental note to which it is tuned, but also vibrating so as to produce overtones. A piano wire tuned to the same pitch produces a different set of overtones, and thus has a quality of its own, and so with each different musical instrument. In the language of wave movement, the pianoforte wire and the violin string may produce the same *number* of waves in a second of time, but the *form* of the wave is different in each case, and so the quality differs.

These are the chief facts to remember regarding sounds. How the knowledge of them aids in the understanding of the structure of the ear and the perception of sound will be seen immediately.

The Organ of Hearing—the Ear.

The **Ear** is to be regarded as an apparatus intended to be affected by waves of sound. Connected with it is the nerve of hearing—indeed the ear is to be considered as a peculiar form of nerve ending—so that as soon as the ear is affected by sound the impression is conveyed along the nerve to the brain, and the sensation of sound is produced. Now the nerve of hearing, or auditory nerve, ends in a peculiar structure placed deeply, for protection, in the bones of the head. So deeply is this principal part of the organ of hearing placed that sounds cannot directly affect it. Some arrangement requires to be provided, therefore, for conveying or conducting the sounds inwards towards the nervous structure. The organ of hearing, therefore, consists of two parts:—

1. A part for conveying sound inwards to
2. The nervous portion affected by sound.

The nervous portion is most deeply placed, and is called the inner ear; while the sound-conducting portion includes what are called **the outer ear** and **the middle ear.**

The **Outer Ear** consists of the appendage, or **auricle,** at the side of the head, and of a passage that leads inwards from it. The outer appendage is of a peculiar shape, which is not without its uses. For it has been shown that waves of sound falling on the outer ear are, owing to its peculiar curves, directed into the passage. The passage, or **external meatus,** is not straight but curved, and is about an inch and a quarter long. Near its outer portion is a number of fine hairs, which may help to prevent the entrance of insects, &c., while in the deeper parts of the canal, embedded in the walls, is a number of glands, resembling the sweat glands (p. 228) of the

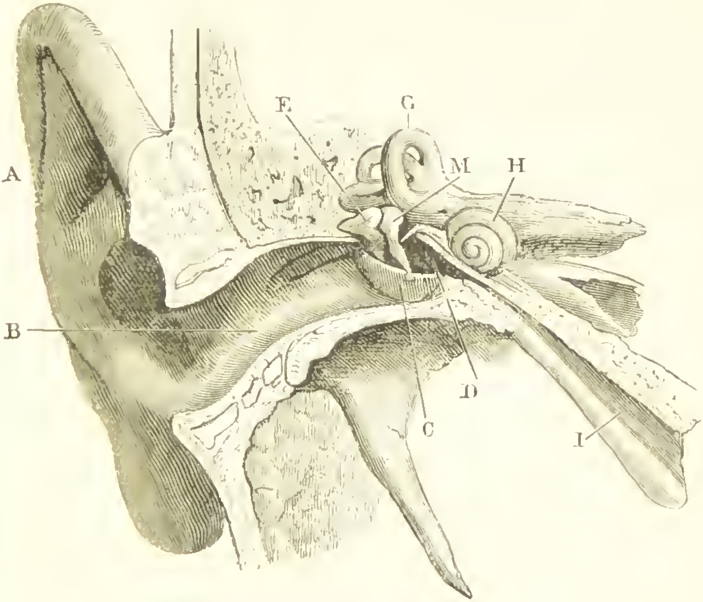


Fig. 120.—The Ear of the Right Side.

A, auricle; B, external canal; C, drum, partly removed; D, cavity of middle ear. E, anvil, and M, hammer—small bones of the middle ear; H, cochlea, and G, semicircular canals of internal ear. [These latter parts are buried in the temporal bone of the head.] I, Eustachian tube passing from the cavity of the middle ear to the throat.

skin, which pour out a yellow waxy substance, the **ear-wax or cerumen.** This substance keeps the canal moist, and may be produced in excessive quantity—for example, owing to irritated conditions of the walls of the canal. as a result of cold—and the wax may collect in sufficient quantity to block the passage and produce dulness of hearing. It is plain that the business of the outer ear is to collect the waves of sound and conduct them inwards nearer to the inner ear, the true organ of hearing.

The Middle Ear.—At the end of the outer ear passage is the **drum of the ear,** or **tympanum,** or **tympanic membrane.** It is stretched quite across the deep end of the passage, which it *completely closes.* It is a thin. unyielding membrane, oval in shape, not flat, but bulging slightly inwards a little below the middle. On the inner side of it is a small cavity, the **cavity of the middle ear,** or cavity of the drum of the ear. This is a small chamber, placed in one of the bones of the head (the petrous portion of the temporal bone, see p. 43), about half an inch in height, and one to two lines in breadth. Its bony walls are lined with mucous membrane—a membrane, that is, similar to that lining the nose, mouth and throat. There are several deficiencies in its walls. In the outer wall an opening in the bone is closed by the drum. The drum, that is to say, is a partition between the passage of the outer ear on one side and the cavity of the middle ear on the inner side. On the inner wall of the chamber are two openings, one round, called the **round window,** or in Latin the **fenestra rotunda,** and another oval, the **oval window, fenestra ovalis.** On one side of the chamber is an opening leading into a tube. about an inch and a half long, the **eustachian tube,** partly made of gristle, and lined with mucous membrane similar to that of the chamber and the throat. This tube passes downwards into the back part of the throat. The tube is usually closed, but it is opened in the act of swallowing. If one firmly closes the nostrils, and performs the act of swallowing, a curious sensation of pressure is felt at the drum of each ear, there is a feeling of great fulness in the ears, and the hearing is not so sharp. If one swallows again, the nostrils being open, the sense of pressure and fulness passes away. The reason is, that by the act of swallowing the pressure of air is increased at the back of the throat, the nostrils being closed, the condensed air cannot escape that way, and rushes up the opened eustachian tubes into the cavities of the middle ear, bulging out the drums and producing the feeling of fulness and pressure. As soon as the act of swallowing is over the tubes close and the air is imprisoned. If swallowing be again performed, the nostrils not being held, the tubes are again opened and the imprisoned air escapes.

It is important to notice that there is, in healthy conditions, no communication whatever between the chamber of the middle ear and the outside except by the eustachian tube. There is no opening between this chamber and the outer passage of the ear in ordinary circumstances, for the drum completely separates the two. But, as a result of disease or accident, an opening may be made in the drum, or the drum may be destroyed, and then of course the middle ear will communicate with the outside through the passage of the outer ear. Another important practical point is that the membrane that lines the throat is continuous up the eustachian tube with the membrane lining the middle chamber of the ear. Thus redness and swelling of the throat—a cold in the throat—is usually accompanied by some degree of deafness, because the swelling passes up to the middle ear, and blocks the chamber.

A chain of small bones—the **auditory ossicles**—extends across the cavity of the middle ear, reaching from the drum in the outer wall to the oval window in the inner wall. These bones are three in number, and from their appearance were called **malleus** or hammer, **incus** or anvil, and **stapes** or stirrup. They are shown in fig. 121, the upper part showing the stirrup-bone, and the lower the bones connected. The resemblance of the third bone to a stirrup is striking. By the long downward projection (2) the hammer-bone (1, 2) is fixed to the inner surface of the drum of the ear, the projection at the side attaching it to the bony wall of the chamber in which it is lodged. The round head (1) of the hammer is connected with the anvil (3) by a movable joint, while the long projection of the anvil (4) is similarly connected with the stirrup-bone (5). The plate of the stirrup is fixed by membrane into the oval window of the inner wall of the chamber of the middle ear. Thus across this chamber this chain of three bones is stretched, placing the two walls of the cavity in communication. Moreover, on the inner side of the oval window is a cavity, part of the internal ear, where is lodged the essential portion of the organ of hearing. The membrane which closes the oval window, therefore, and to which is fixed the plate of the stirrup, separates the cavity of the middle ear from the internal ear.

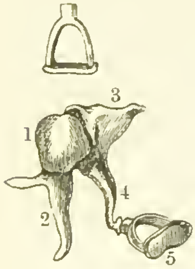


Fig. 121.—Ear-bones.

The purpose of the external and middle portions of the ear now becomes evident. Waves of sound are produced in the atmosphere about us. These waves reach us, and are directed by the appendage of the ear up the external passage, at the end of which they meet the drum. The drum is a thin membrane, and, when waves of sound beat upon it, it is thrown into vibration, reproducing, it is to be remarked, in its movements the characters of the sound-waves that have fallen upon it. But to the inner surface of the drum is attached one end of the chain of bones, and since that chain is movable, the vibrations of the drum will be passed along the chain and reach the stirrup. The stirrup fits into the oval window by means of a membrane, and the stirrup and membrane will consequently be caused to perform to-and-fro movements at the oval window, passing the movement inwards to the structures of the internal ear beyond. Thus by means of the external appendage, the external canal, the drum, and the chain of bones, the movements in the air caused by a sounding body are communicated to the internal ear.

It may be added that three small muscles are connected with the chain of bones. Two are connected with the hammer, one (the **tensor tympani**) so pulls on it as to tighten the drum to which it is attached, the other pulls in the opposite direction and relaxes the drum (the **laxator tympani**). One small muscle is attached to the stirrup (the **stapedius**) whose contraction prevents the stirrup being pushed too deeply into the oval window. The external and middle parts of the ear evidently form a *sound-conducting apparatus.*

Having seen how sound is conducted to the internal ear, we must now see what arrangements exist in that part for receiving the sounds led to it.

The **Internal Ear** consists of a curiously shaped structure buried in the temporal bone (p. 43). It is represented in fig. 122. The opening, marked 2, is that of the oval window, on the inner wall, as we have seen, of the cavity of the middle ear, and closed by the stirrup-bone and its membrane. This opening leads into a small chamber, about $\frac{1}{5}$th of an inch in diameter, called the **vestibule.** From the back part of the vestibule there open three tubes, the **semicircular canals,** so called because of their shape, which are $\frac{1}{20}$th of an inch in width and make a curve of about $\frac{1}{4}$th of an inch in diameter. One is directed horizontally (4), another upwards (3), and the third backwards (5). Opening from the vestibule by these separate openings, they also join it again. The upper

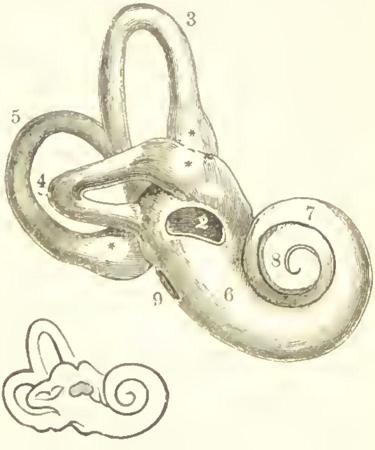


Fig. 122.—Bony Internal Ear of the right side; the upper figure magnified, the lower of the natural size.

and back one are united at the other end and rejoin the vestibule by a common opening. Thus there are five openings connected with the canals. Each canal has a bulging part at one end called an **ampulla**, marked thus * in the figure. From the fore part of the vestibule there passes a tube, which makes two and a half turns, coiling like a snail's shell. It is termed the **cochlea** (6. 7, 8, fig. 122). At the base of the cochlea is the opening of the **round window** (9, fig. 122) which communicates with the cavity of the middle ear (p. 348), but in the recent state is closed by a membrane. Besides the openings already mentioned, the vestibule has several small apertures in its inner wall, by means of which there enter branches of the nerve of hearing—auditory nerve (p. 279). All these parts, vestibule, semicircular canals, and cochlea, are formed of bone, and to the whole structure the term **bony** or **osseous labyrinth** is applied. The inner surface is lined by membrane, and the labyrinth contains a fluid, the **perilymph**.

But this bony labyrinth forms only an outer casing for a membranous labyrinth. Fig. 123 represents the complete membranous labyrinth. It is formed of two sacs which are lodged in the bony vestibule. The larger of these sacs (*d*) is called the **utricle**, the smaller the **saccule** (*e*). These, it is to be remembered, are lodged in the bony parts described, and separated from the bony walls by the fluid — perilymph — contained in the bony labyrinth. Passing off from the utricle (*d*) are membranous semicircular canals (*a*, *b*, *c*), lying in the bony canals of the same name, surrounded by the perilymph. The inner surface of the utricle and membranous canals is lined by epithelial cells (p. 31), and from the surface fine hairs project into the interior, which contains a fluid—the **endolymph**. Branches of the nerve

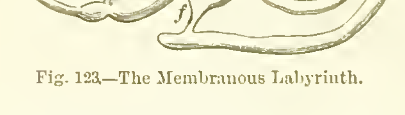


Fig. 123.—The Membranous Labyrinth.

of hearing pass to the sac and canals, and are supposed to be in connection with the hair-like processes. The nerves are specially distributed to the sac and the bulgings of the membranous tubes. Now if these hair-like processes are connected with nerve-fibres, the slightest agitation of the fluid in the membranous canals will disturb the hairs and consequently affect the fibres of the nerve of hearing. Within the sac of the utricle are found minute crystals of carbonate of lime—**otoliths**—which may be supposed, on disturbance of the fluid, to affect more strongly the hair-like projections from the walls.

The smaller sac, the saccule (*e*), lodged also in the bony vestibule, communicates by a fine canal (*f*) with the membranous canal (*g*) contained in the shell-like bony cochlea, and called the **canal of the cochlea**. Further, it is found that the two sacs communicate with one another by a very fine tube, so that the whole membranous labyrinth is connected together.

The **membranous canal of the cochlea** (*g*) is the most important part of the internal ear, since in it is lodged the apparatus that is believed to be the chief agent in the perception of sound. It has already been mentioned that the cochlea possesses an outer bony case, resembling in appearance the shell of a snail (6, 7, 8 of fig. 122). But we must now describe this bony part rather more particularly. If the cochlea be opened into, there is seen to be a central bony pillar, round which the bony tube is wound two and a half times. The central bony pillar is called the **modiolus**. The bony tube is not regular inside. From that part of it which lies against the central column, as it winds round, there projects inwards a bony ridge—the **lamina spiralis**. At the base of the bony cochlea, just where it begins to wind round the modiolus, this ridge projects well into the space of the bony canal,

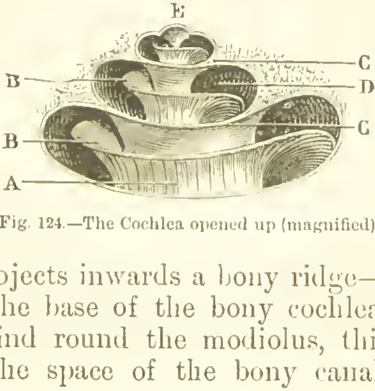


Fig. 124.—The Cochlea opened up (magnified).

dividing it almost into two compartments; but as the bony canal winds round the column, the lamina spiralis, which, of course, follows the turnings, becomes less and less projecting, till at the blind end of the bony cochlea it is not nearly so prominent. Fig. 124 shows the cochlea with part of the wall removed to show the interior. From E straight downwards is the direction of the central column—modiolus—to which D points: B B point to the projecting ridge—lamina spiralis—almost dividing the canal of the tube into an upper compartment C and a lower A. (Refer also to fig. 125.) Now in the recent state this partial division of the tube is completed by membranes, so arranged as to form a membranous canal within the bony one—the **membranous canal of the cochlea.** This will be understood from fig. 125. This represents the cochlea cut straight down from top to bottom. M is the central column; A, B, C, and D are complete sections of the bony cochlea, in different parts of its winding, cut across. Each cross section shows the lamina spiralis, marked L in one section, projecting inwards from the central column. From the edge of this ridge two lines (1 and 2) are seen passing outwards, and diverging as they pass, to the outer wall of the bony canal. These are membranes; the lower (1) is called the **basilar membrane,** the upper (2) is the **membrane of Reissner.** These two membranes thus complete the division between the upper and lower part of the bony tube. The upper division (S.V.) is termed the **scala vestibuli** (the staircase of the vestibule) the lower (S.T.) is the **scala tympani** (the staircase of the tympanum). Inasmuch, however, as the

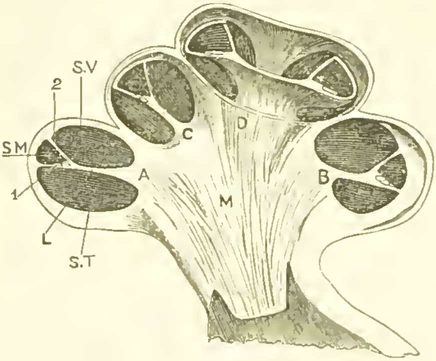


Fig. 125.—Vertical Section of the Cochlea of a Fœtal Calf.

two membranes separate from one another as they pass across, they inclose between them a triangular space. It is this space (S.M.), formed by the basilar and Reissner's membranes and the part of the bony wall between them, that constitutes the membranous canal of the cochlea, or the **scala media** (middle staircase) of the cochlea. This part of the bony wall is, like the rest of it, lined by a membrane. Thus we have the bony cochlea throughout its two and a half turns divided into three compartments; and within the bony canal of the cochlea we have a membranous canal, occupying only a small part of the space. Now at the base of the cochlea, that is, at the beginning of the first turn, the scala of the vestibule opens into the bony vestibule already described, while at the foot of the scala of the tympanum is the round window, closed and separated from the cavity of the middle ear by a membrane. As we have seen, the vestibule has an opening in its wall—the oval window—on the outer side of which is the cavity of the middle ear, but which is closed in the fresh state by the stirrup-bone and its membrane. At the top of the cochlea the scala vestibuli and the scala tympani communicate with one another by a small opening called the **helicotrema**.

Suppose, then, we begin with the external canal of the ear. Passing up it for an inch and a quarter we reach the drum. On the inner side of the drum is the cavity of the middle ear, across which stretches the chain of small bones, one end of which is attached to the inner surface of the drum, and the other end of which—the stirrup—is inserted into the oval window. On the inner side of the oval window is the bony chamber of the vestibule, opening from which is the scala vestibuli. Entering this staircase we pass round two turns and a half to the top of the cochlea. Part of the floor of this scala is the membrane of Reissner, which is also the roof of the scala media. Reaching the top we pass through the small opening of the helicotrema, and enter the scala tympani, down which we pass two turns and a half. Part of the roof of this staircase is the basilar membrane or floor of the scala media, which is thus inclosed between the two staircases. Arrived at the foot of the scala tympani we reach the round window, closed by a membrane, on the outer side of which is the cavity of the middle ear.

Next it is to be observed that the scala vestibuli and scala tympani are both filled with a fluid—perilymph. Consequently waves of sound in the atmosphere pass up the external passage and throw the drum of the ear into vibration. These movements are conducted across the chain of bones to the oval window, and cause the stirrup-bone to make to-and-fro movements at the window. These throw the fluid in the vestibule into vibrations, which pass up the one staircase and down the other and are spent at the round window. As these waves pass along the fluid they communicate movement to the membrane of Reissner, the floor of the vestibule staircase, and to the basilar membrane, the roof of the tympanic staircase. These membranes are respectively the roof and floor of the middle scala or membranous canal, and this canal also is filled with fluid—endolymph—which is consequently agitated. Consequently the vibrations of a sounding body ultimately communicate movement to the fluid contained in the membranous canal or middle staircase.

The membranous canal of the cochlea then lies in the bony cochlea, inclosed between the two staircases. but it does not open into either. At the top of the cochlea it ends blindly. Its base lies in the bony vestibule. but does not open into it. By a small canal (*f*, fig. 123). however, it has connection with the saccule.

Within this membranous canal and resting on the basilar membrane is a remarkable structure, first described by the Marquis Corti, and hence called **Corti's organ**. It is a very complicated structure, which it is needless to try to describe here. It consists mainly of a series of fibres—**fibres of Corti**—each made of two parts resting against one another so as to form an arch. These arches are placed, side by side, in a continuous series along the whole length of the basilar membrane. In the human ear it has been estimated that there are no less than 3000 of such arches. When viewed from above downwards by a microscope, they present the appearance of the key-board of a piano. Fig. 126 A shows a few of the arches side by side, B of the figure exhibiting two fibres forming an arch. It would appear that the arches are supporting structures. For, resting on them, are numbers of conical epithelial cells from the free surface of which bundles of stiff hairs (cilia) project. It is believed that these hair cells are the true sound-perceiving structures.

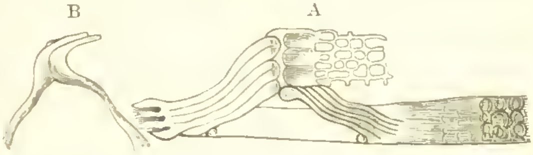


Fig. 126.—Arches of Corti's Organ (very highly magnified).

We have seen how vibrations of a sounding body reach, in the end, the membranous canal of the cochlea, containing Corti's organ. The fluid contained in this canal will be thrown into vibrations, and these in turn will affect the hairs of the cells supported on Corti's rods. These hair cells are in communication with nerve-fibres, which pass into Corti's organ through channels in the modiolus, or bony pillar round which the cochlea is wound. Thus the vibrations communicated to the hairs will affect the nerve-fibres, and cause messages to be sent along the nerves to the brain, resulting in sensations of sound.

The Sense of Hearing.

The Perception of Sound.—The description that has been given of the very complicated structure of the ear will enable one to perceive how sounds are conveyed into the depths of the ear, but it is extremely difficult to understand how that apparatus enables us to have knowledge of all the multitude of various sounds of which we are daily conscious.

We must go back again to the physical world to get light on the difficulty. It is a well-known fact that if one takes two tuning-forks, such as are used for experiment in a natural philosophy laboratory, both tuned to sound exactly the same note, and if the forks are placed at some distance from one another, and one of them is made to sound, the other not being touched, in an instant both will be heard sounding. The sound of the one fork has set the other agoing. This, it must be noticed. happens only if both utter a note of the same pitch. If the two forks sound different notes, the one may be set humming loudly and long, the other remains dumb. But if the two are tuned to the same note the one is no sooner set sounding than the other is heard humming also. This is called **sympathetic vibration**, but there is no mystery about the occurrence. The one fork produces waves exactly similar to those the other would produce. When, therefore, one is sounded, the waves pass out and reach the other fork, against which they strike. Wave after wave hitting on the fork, each wave exactly suiting the swing the fork makes when in motion, gradually sets it into vibration. It is just like a small boy setting in motion a swing on which a heavy boy is sitting. If he tried to make it give a big swing with one push, he might push with all his might and accomplish nothing. If he be a wise small boy, however, he does not attempt this. He gives the swing an ordinary push, and it swings slightly. He waits till it has moved forward, then backwards, and just as it is about to sway forwards again. he gives it another push, which, added to its own impulse, increases its movement. So he goes on till, in a short time, he has it in full swing. But if he does not time his pushes properly he will speedily stop the swing. It is the same with the tuning-fork. Each wave from its neighbour reaches it at the proper time and speedily sets it in full vibration. If now the second fork have one limb loaded, say with a piece of wax, the note of the fork is flattened. It is no longer in tune with the first one. and can no longer be set in sympathetic vibration with it, because its swing is no longer in time with the waves of its neighbour. One fork, therefore, can be set in vibration only by another sounding exactly the same note; and the fork will recognize its own note and hum in harmony with it, though the sound reach it from a considerable distance.

Suppose, then, that, on a table at one end of a room, one had a set of tuning-forks, each tuned to a particular note. Let a number of musicians proceed to play on their instruments at the other end of the room. No matter how complex the body of sound they produce, each tuning-fork will pick out infallibly its own note from the mass of sound, if its own note happens to have been produced; and, if the players suddenly cease, the tuning-forks will be heard sounding. By finding which of them are vibrating, one can tell what notes were produced by the players. Suppose one could have a set of tuning-forks, so numerous that there was one for every note that could be sounded, it is evident one would have here an apparatus for analysing the complex sound, that is, splitting it up into its elements. One may try a simple experiment of this kind with a piano. Let the damping pedal be lifted from the wires, and let someone sing loudly in the room, and then suddenly stop. Some of the pianoforte wires will be heard sounding. They have picked out of the song their own notes, and have been set in sympathetic vibration by them.

Now it is believed that it is somewhat after this fashion that the internal ear perceives sound. It has been noted (p. 357) that, in the internal ear, the organ of Corti contains a large number of cells with hairs projecting from them. It is supposed that each hair is sensitive to a particular vibration. The vibrations of a sounding body are conducted to the internal ear in the manner already described, and agitate the fluid in the membranous canal of the cochlea. The waves produced will be complex waves, compounded that is of simple waves of different lengths, &c. Each hair, however, will vibrate in harmony with one particular simple wave, and if that one be contained in the complex one, it will pick it out and vibrate to it. Thus the complex wave of sound will be split up into simpler forms, each hair selecting and vibrating to its own, and a multitude of hairs will be set simultaneously vibrating by the mass of sound. The ear is thus an organ that analyses (splits up) sounds into their elements.

In support of this view it may be mentioned that hairs on the feelers of the Mysis, an animal belonging to the same general class as crabs and lobsters, have been seen to vibrate in harmony with particular notes and with these notes only.

Each hair cell is in communication with a nerve-fibre, and the vibration of each hair will thus cause an impression to be passed along a nerve. The various impressions will be passed along to the hearing centre in the brain, where they become fused, and the person is conscious of a sound of a particular kind. While the ear splits up complex sounds, and communicates to the brain the elements of which they consist, the brain reunites them. We are not usually conscious of the splitting-up process but only of the union.

The **Range of the Ear** for musical sounds has been determined to be from 32 to about 30,000 vibrations per second. That is to say, 32 vibrations per second produce the sensation of a low musical note, the lowest the human ear can appreciate, while vibrations occurring at the rate of about 30,000 per second produce the sensation of a very high pitch, the highest the human ear can appreciate. Vibrations more rapid cannot be taken knowledge of by the ear.

The **Sensation of Discord** in music is due to the interference of two sounds which are nearly of the same pitch. As two waves in water may abolish one another if the crest of one meets the hollow of another, and may again add to one another's size by the two crests meeting, so two waves of sound, differing slightly from one another, may at one moment almost extinguish the sound by interference and at the next produce increased loudness of the sound by being added to one another. The result is the production of what in music is called **beats**, characterized by a rising and falling of the sound. The effect on the ear is similar to the effect of a flickering light on the eye. When the beats occur with sufficient rapidity they give a sensation of roughness to the sound, greatest when they number 33 in a second. When they reach the number of 132 in a second they are no longer perceived. Two notes, that when sounded together produce beats, are recognized as discordant notes.

Judgments of the direction of sound are not actually performed by the ear; they are the result of various other circumstances. Anyone can prove this by shutting the eyes and trying to decide the direction from which a sound is coming. The distance from which a sound proceeds we judge of by its loudness or faintness. It is such facts as these that the ventriloquist takes advantage of to deceive people. He imitates the character of sound from a distance, or from some particular place, by giving it the required degree of loudness, and by directing the attention of the person to that quarter, &c., his own face at the same time giving no sign of movement.

"Educating the ear" is a phrase which derives force from all that is known about the mode of action of the organ of hearing. We have seen that the ear actually analyses or splits up sounds into their simple elements, and that the brain fuses the elements together again. The habit is to pay attention only to the fused sensation. But we all know that the trained musician detects the elements of a complex sound, while the person who has given no attention to his sensations knows only, perhaps, that the sound is pleasant or the reverse. Just as surely as every ear performs the same process of analysis, so may every person, by careful training, become able to perceive something of the analysis, and to detect some of the varied elements of musical sounds that he listens to.

CHAPTER XIV.—REPRODUCTION.

Reproduction is the process by which the species is propagated. In the lowest forms of life there are no sexes, and each individual possesses the power of reproducing its kind. Thus the minute organisms, called germs, multiply many of them by **fission**. The individual is divided into two by a constriction appearing in the middle, which deepens until the two halves are separated, each half becoming an independent being. The yeast-plant, which consists of a single cell, multiplies by throwing off a bud, which, when it has separated from the parent cell, is a separate individual. This is multiplication by **gemmation** or budding. Other cellular organisms multiply by what is called **endogenous formation**. A number of daughter cells, as the term is, are formed in the parent cell, and liberated by its rupture. Among animals having a backbone only sexual reproduction occurs. The new individual results from the union of two elements—one derived from the female—the ovum, the other derived from the male—the spermatozöon. The ova are developed in special organs—the ovaries, and in the females of the higher animals there is an organ—the womb, set apart for retaining the developing offspring till it reaches a stage when it may enter upon an independent existence. The union of the male and female elements is called **fecundation**, and immediately following it a series of remarkable changes occurs in the ovum. This is originally, in the human being, a minute cell, $\frac{1}{120}$th inch in diameter, possessing a transparent envelope, a nucleus, and nucleolus (see p. 28). After fecundation this one cell divides into two, each of the two divide and so four are produced, each of the four divide and thus eight are produced, and so on to 16, 32, 64, &c., till a small mulberry-like mass of cells results, from which the various parts of the new being are developed. The ovum meanwhile descends from the ovary along a fine tube—the **fallopian tube**, to the uterus prepared to receive it. Here it is retained for a season. Partly from the walls of the ovum and partly from the wall of the womb membranes are developed which inclose the ovum as a bag. Fluid is produced within the membranes, and thus the growing offspring, at this stage called an **embryo**, is surrounded by fluid within a membranous bag or sac. From the same walls a structure, called the **placenta**, is developed, by which the embryo is kept in relation with the mother. The placenta at its full stage of development measures 7 or 8 inches in diameter. It consists of a part which is an overgrowth from the walls of the womb, namely a very spongy tissue containing large spaces in which the blood of the mother flows, and of a part, consisting of elongated finger-like processes dipping into the blood-spaces, derived from the embryo and its membranes. In these processes circulates the blood of the embryo. Thus the blood of the offspring and that of the mother are brought into relationship with one another, separated only by the thin walls of the vessels and the tissue of the processes. Exchanges take place, and the nourishment of the blood of the offspring is maintained by that of the mother. In the later stages of growth the offspring is called a **fœtus**. The fœtus, inclosed within the womb, cannot use its lungs; and its blood is aerated by exchanges with the blood of the mother. As soon as it is born and enters upon a separate existence, its lungs come into play, and, as one would expect, there are considerable differences in the circulation of blood in the fœtus and in that of the newly-born child.

The fœtus is connected to the placenta by a cord, the **umbilical cord**, attached at the navel. In this cord run two arteries and a vein, the arteries twisting round the vein; and they are embedded in a jelly-like tissue. The arteries arise within the pelvis of the fœtus, and, running up the front of the abdomen, they pass into the cord and on to the placenta. The blood which they carry circulates in the finger-shaped processes of the placenta, which dip into the blood-spaces already referred to, and effect exchanges with the blood of the mother. The blood, now oxygenated, returns in the umbilical vein to the fœtus, and, entering at the navel, passes partly to the portal vein of the liver (p. 106) and partly passes on to the inferior vena cava (p. 158) by a special vessel, the **ductus venosus.** In the end, therefore, all the blood returned from the placenta reaches the inferior cava, and thence passes to the right auricle of the heart. *Thence it does not descend into the right ventricle. An opening exists in the fœtus—the* **foramen ovale**—*between the right and left auricles, and the current of blood is directed through this opening into the left auricle.* From there it passes into the left ventricle and issues into the aorta, going on to the head, neck, and upper limbs, none passing down the descending part of the aorta to the lower limbs. From the head, neck, and upper limbs the blood returns by the superior vena cava to the right auricle. *Here it crosses the current going through the foramen ovale,* and enters the right ventricle, and from there passes into the pulmonary artery. The branches of the pulmonary artery to the lungs are small in the fœtus, the lungs being inactive, and by a special branch, the **ductus arteriosus,** the blood passes straight to the aorta at the place where it turns to pass down the body. Thus a little only of the blood passes to the lungs. The main portion crosses through the ductus arteriosus into the aorta and by it is distributed to the lower parts of the body, reaching the arteries which again convey it to the placenta. When the child is born the circulation through the cord and placenta ceases and various other things happen. The continuation of the umbilical vein as the ductus venosus is obliterated. The foramen ovale is closed by a valve. By the act of breathing the lungs become distended, the pulmonary arteries become filled with blood and expand, and blood ceases to flow through the ductus arteriosus, which dwindles to a cord. Thus the blood from both inferior and superior venæ cavæ mingles in the right auricle instead of keeping separate, passes to the right ventricle, thence through the lungs to the left auricle, down into the left ventricle, and from thence is distributed throughout the body, as described on p. 159.

Lactation.—The process by which milk is formed is called lactation. It is a process of secretion (p. 92), and the glands of the breast which form the milk are called the **mammary glands.** They are racemose glands (p. 93). The milk, when formed, finds its way to the outside by from fifteen to twenty small ducts or channels which open separately on the nipple. Each duct has a little dilatation or reservoir about one or two inches from its mouth. and passing inwards from that it branches repeatedly. The finest branches end in minute pouches, very thin-walled and lined with a single layer of active cells. On the other side of the thin walls are numerous blood-vessels. The cells thus obtain a plentiful supply of blood from which to elaborate the milk. The composition of cow's milk is shown on p. 84. Human milk contains more water, more sugar, but less proteid material butter and salts, so that cow's milk for infants' use is made more nearly to resemble human by being diluted with water and by a slight addition of sugar. Milk, when viewed under the microscope, appears as an opaque fluid, with numerous oil globules of various sizes floating in it. When milk is churned, the envelopes of albumin surrounding the oil globules are broken, the oil globules then run together and the masses of butter are thus separated.

Milk is usually produced in abundance by the female breasts within three days after childbirth, and the average daily quantity produced is $1\frac{3}{4}$ pints.

DEATH.

Constantly during the life of the individual, the minute elements of the body undergo waste, die, and are replaced by others. Death is thus a necessity of life so far as the elements of the body are concerned. If from a limited part of the body, such as a finger, a toe, part of the skin, &c., the blood supply be cut off, the nutrition of the part is immediately arrested. It dies and is separated as a slough. This is local death; and a large mass of tissue may be so separated from the body without materially affecting the life of the body as a whole, provided the part be not essential to continued existence. Local death is thus the result of interference with the nutrition of the part. But the nutrition of the whole body may be profoundly affected, as by high fever, some exhausting disease, blood poisoning, &c., and the death of the body as a whole may result. If the heart become so enfeebled that it cannot circulate the nourishing fluid efficiently, or if it suddenly cease the performance of its duty, death occurs. If the lungs be seriously impeded in their work, oxygen is not duly introduced, the whole of the nutritive processes are impaired, and again death arises. Interference with heart or lungs will thus speedily issue in general death. We have seen that it is the stimulus of the nervous system that maintains all the organs in due activity; and if this be withdrawn or seriously modified, a similar result will quickly ensue. Thus it is that death is said to begin at the heart, lungs, or brain, which constitute the tripod of life. It is also evident that the processes of nutrition may go on actively even though the individual be in a state of profound unconsciousness, so that consciousness is not necessary to life.

EXAMINATION PAPERS.

1890.

First Stage or Elementary Examination.

1. What structures form the walls of the thorax or chest? How is the thorax made air-tight? What important viscera are contained in it, and what positions do they occupy in it? Explain how changes in the diaphragm alter the size of the thorax. (15.)
2. If a heart, a sheep's heart for instance, removed from the body, were put before you, how could you tell which was the top, which the bottom, which the front, and which the back? What are the chief differences between the left ventricle and the right ventricle, and what purposes are served by these differences? (15.)
3. What is the spinal cord? Where is it placed? Explain how the spinal cord is protected from injury by the structure and arrangements of the walls of the cavity in which it lies. (15.)
4. Of what chemical elements are fat and starch composed? How do fat and starch differ from each other? What changes does starch and what changes does fat undergo in the alimentary canal? Where and how are those changes brought about? (15.)
5. What is the most important substance and, next to the water, the most abundant substance present in urine? Of what chemical elements is this substance composed, and how does it come about that the kidneys are always, to a greater or less extent, engaged in secreting this substance? (10.)
6. What do the red and white corpuscles of the blood look like when a drop of blood is examined under a high power of the microscope, and how do they differ from each other? State an important use of the red corpuscles. (10.)
7. How in a *dead* body can you tell an artery from a vein? What are the chief differences between them, and why are they thus different? (10.)
8. What are the two chief parts of the skin, and how do they differ from each other? How does the skin of the lip differ from the skin of the heel, and why? (10.)
9. What differences can be observed, without the aid of any microscope, between (*a*) a bone just fresh from the body, (*b*) one which had been dried and kept for some time, and (*c*) one which had been steeped in acid for some time? (10.)
10. What is meant, in speaking of vision, by "the blind spot," and how can its presence be demonstrated? What conclusions concerning the nature of sight can be drawn from the existence of the blind spot? (10.)

11. What parts go to form the hip-joint? What movements of the hip-joint can be carried out? How are they limited, and why? (10.)
12. Describe the course taken by the air in breathing until it reaches the glottis or pharynx, and explain why it is better to breathe through the nose than through the mouth. (10.)

Second Stage or Advanced Examination.

21. Describe the general features, the minute structure, and the properties of a medium-sized artery and of a medium-sized vein. Explain how a microscopic artery just about to divide into capillaries and a microscopic vein just emerging from capillaries differ respectively from the above. Point out how the differences in structure between an artery and vein correspond to differences in function. (26.)
22. What gases are present in arterial and in venous blood, and to what amount in each? State how the results you give are arrived at. Explain how blood is able to contain such relatively large quantities of oxygen and carbonic acid, and point out the importance of this in the respiratory changes in the lungs and in the tissues. What is meant by dyspnoea and asphyxia? What respiratory movements are respectively characteristic of these two conditions and how are they brought about? (26.)
23. Describe the microscopic structure of the stomach, pointing out the differences between the mucous membrane at the cardiac end and that at the pyloric end. What appearances are presented by the glands before and during or after secretion, and what conclusions may be drawn from these appearances concerning the act of secretion? (16.)
24. In what parts of the body, and by what processes, is heat produced, and how is heat lost to the body? Explain the various means by which the bodily temperature of a "warm-blooded" animal is kept constant under varying conditions. (16.)
25. Give an account of the general structure of the brain, confining yourself to a brief statement of the general nature and form of the chief parts, and of their relations to each other. What actions can a frog, deprived of the cerebral hemispheres, carry out, and what can it not carry out? (16.)
26. Describe the structure of the spleen. Give an account of the changes in bulk which it undergoes under various circumstances. Explain how these are brought out, and what is their probable significance.
27. Describe the form, position, and structure of the semicircular canals. What is the evidence that they possess functions other than those connected with hearing? (16.)
28. We are in the habit of recognizing certain distinct sensations which we speak of as sensations of so many different colours,

hues, or tints. What is the evidence that these several sensations are not simple sensations, but are compounded of certain "simple" or "primary" sensations, mixed in different proportions? Point out the bearing of this on the explanation of colour blindness. (16.)

1891.

First Stage or Elementary Examination.

1. Describe the form, position, and general appearance of the sternum. What is the nature of the material of which it is composed? What changes of position does it undergo in breathing? (15.)
2. Give an account of what may be seen by examining the right auricle of the heart from the outside. State how you would proceed to lay open the cavity of the right auricle in order to show to the best advantage the structure and relations of the auricle, and carefully describe what may be seen in the auricle thus laid open. (15.)
3. Describe the form, position, and general structure of the small intestine. How does the small intestine differ from the large intestine? State briefly the changes which the food undergoes (1) in the small (2) in the large intestine. (15.)
4. Give an account of a valve in a vein, describing how it appears when seen by the naked eye or with the help of a lens. Describe its nature, and explain how it works. Which veins possess many valves, which few, and which none at all? (15.)
5. What is the nature of cartilage? How does it differ from bone, and from tendon? State as fully as you can in what parts of a full-grown body cartilage is found. (10.)
6. Describe the portal vein, stating how it begins, where it runs, and how it ends. Does the blood as it passes along the portal vein after a full meal has been taken, differ from the blood passing along the same vein when no food has been taken for some time; and if so, how? (10.)
7. What is the structure of the diaphragm? How does the diaphragm act in breathing? (10.)
8. What is a clot of blood composed of? When you cut a large clot of blood open, does the inside look different from the outside; and if so, why? How may a colourless clot be obtained? (10.)
9. When you touch a body with your finger you can tell whether the body is rough or smooth; why cannot you do this if the skin of the finger be injured or removed? In what part of the body is the sense of touch most acute, and in what parts least? How can you determine this accurately? (10.)
10. What is the general structure of the spinal cord? Explain what happens if the spinal cord be damaged (1) at the level

of the bottom of the neck (2) at the level of the middle of the back. (10.)

11. Explain as fully as you can what you do when you "hold your breath." What changes are taking place in your lungs while you are holding your breath? Why cannot you hold it for more than a very short time? (10.)
12. After violent exercise a man says "he is very hot." Is he really hotter than usual? If not, explain how this is? (10.)

Second Stage or Advanced Examination.

21. Describe the structure of the lung, dwelling more especially on the features of a pulmonary alveolus. Explain exactly why the lung shrinks when the pleural cavity is laid freely open, and why the movements of the chest are then unable to promote the respiratory interchanges between the blood and the air, so that suffocation ensues. About how much air still remains in the lung after a free opening into the pleural cavity? Why does it remain? Under what circumstances may it wholly disappear? (26.)
22. Describe the structure of the spinal cord at the level of about the middle of the thorax, and compare the cord in this region with the cord in the cervical swelling and in the lumbar swelling. What is the evidence that the efferent impulses which carry out voluntary movements of the skeletal muscles pass along a definite tract of the spinal cord? (26.)
23. Give an account of the structure of the large intestine, pointing out the most important differences between it and the small intestine. Describe briefly the changes undergone by the food in the large intestine. (16.)
24. Explain how the flow of blood through a part of the body, through a limb for instance, is governed by the nervous system, showing how, by means of nerves distributed to the limb, the flow may be either increased or lessened. Point out the effects of such increased or lessened flow on the temperature of the limb. (16.)
25. Describe the structure of a lobule of the liver and state how the structural features and chemical nature of the liver of an animal which had recently been fed on a full meal would differ from those of the liver of an animal which had received no food for a long time. (16.)
26 Describe the structure of the iris. State the changes in the iris which determine the size of the pupil, and explain (1) why the pupil widens and narrows according to the amount of light falling into the eye: (2) why a powerful emotion, such as fear, leads to a widening of the pupils. (16.)
27. Describe the structure of a salivary gland, and the changes which take place in it while saliva is being secreted by it? (16.)

28. What is the composition of sweat? Describe the structure of the organs which secrete it, and explain why exposure to a high temperature, violent exercise, and a powerful emotion severally lead to sweating. (16.)

1892.

First Stage or Elementary Examination.

1. What is the abdomen? What structures form its walls? State the more important organs which are placed in the abdomen, giving the position of each, and explaining in particular the manner in which the alimentary canal passes through the abdomen. (15.)
2. Describe the semilunar valves of the aorta, stating their exact position, their appearance, form, and structure (as far as the latter can be made out without a microscope), and explaining how they act in the work of the circulation. (15.)
3. Explain how the chest is enlarged when we breathe in, and how it becomes small again when we breathe out, and show why air goes into the chest in breathing in, and why it comes out in breathing out. About how far into the chest does the air which we take in at an ordinary breath go? (15.)
4. What is the general structure of the mucous membrane of the stomach, and what are the characters of the juice which it secretes? Describe the changes which a piece of meat and a piece of bread undergo in the stomach. (15.)
5. How would a cupful of blood drawn from some artery in a limb, say the artery in the thigh, differ in appearance from a cupful of blood drawn from the neighbouring vein? To what important changes undergone by the blood in passing from the artery to the vein is this difference of appearance due? Where and how have these changes been brought about? (10.)
6. State the structure of a muscle and of its tendon as far as can be made out without the use of a microscope. What happens to the muscle and to the tendon when the muscle contracts? (10.)
7. What is bile? Where is it formed? Where does it flow to when food has recently been taken, and where does it go when food has not been taken? What are its chief uses? (10.)
8. In what parts of the body are capillary blood-vessels most abundant and most close set? In what parts of the body are they scanty and far apart? From what parts of the body are capillaries entirely absent? (10.)
9. What is the crystalline lens? Where is it placed? What is its use? When and why does it change in shape? How is the change brought about? (10.)
10. Describe the general structure of a kidney, and state the general

nature of the work which the kidneys perform. If the kidneys fail to excrete urine what changes take place in the blood? (10.)

11. What do you understand by absorption from the alimentary canal? What are the things which are absorbed from the alimentary canal? What are the two paths along one or other of which the absorbed matters travel, and whither does the one and the other lead them? (10.)
12. Explain how it is that when a man "breaks his neck" he dies at once, but if he "breaks his back" he may live for a long while afterwards. (10.)
13. If a person who is standing or sitting up feels faint, what is the best thing to do to prevent his fainting? Explain the reason of the measures which you would adopt. (10.)

Second Stage or Advanced Examination.

21. Give an account of the structure and chemical composition of the corpuscles of the blood. State what is known of the life-history of, and the purposes in the economy served by, the red and white corpuscles respectively. (26.)
22. Describe the structure, gross and minute, of the kidney. Explain the nature of the process of the secretion of urine, pointing out the probable functions of the several renal structures. (26.)
23. Describe the structure of a villus, and the changes which take place in it during intestinal digestion, dwelling on the manner in which proteids, carbohydrates, fats, salts, and water are respectively absorbed. (16.)
24. Describe the more important features of the right auricle of the heart, state the events taking place in it during a whole beat of the heart, and point out the uses of the auricle in the work of the circulation. (16.)
25. State the several parts of the nervous system concerned in carrying out an ordinary breath (an ordinary inspiration followed by an ordinary expiration), and explain how the several parts work. Trace out the chain of events through which (*a*) an imperfect supply of pure air, (*b*) powerful emotions, disturb calm breathing. (16.)
26. Describe the structure of a ganglion on the posterior root of a spinal nerve, and state what is definitely known as to the function of such a ganglion. (16.)
27. State the changes which may be observed to take place in an eye, when "accommodation" for a distant object takes place, and explain how these changes are brought about. (16.)
28. Give a brief sketch of the structure of the larynx and of its condition, when easy breathing, in the absence of voice, is taking place. Explain the nature of the changes which take place when vocal sounds of low pitch and of high pitch are uttered. (16.)

DESCRIPTION OF THE PLATES.

ILLUSTRATIONS OF TERMS APPLIED TO THE BONES AND MUSCLES OF THE HUMAN BODY.

THE SKELETON (Fig. 1).

1. Frontal bone.
2. Parietal bone.
3. Temporal bone.
4. Coronal suture.
5. Malar or cheek-bone.
6. Nasal bones.
7. Superior maxillary—Upper jaw-bone.
8. Orbits.
9. Side of occipital bone.
10. Condyloid process of lower jaw.
11. Angle of lower jaw.
12. Symphysis of lower jaw.
13. Four lower cervical vertebræ (7 in all).
14. Two upper and two lower dorsal vertebræ (12 in all).
15. Lumbar vertebræ (5 in number).
16. Sacrum.
17. Coccyx.
18. Cartilages of ribs.
19. Ribs.
20. First bone of sternum } Breast-bones.
21. Second bone of sternum }
22. Ensiform cartilage.
23. Clavicles—Collar-bones.
24. Coracoid process of scapula—Shoulder-blade.
25. Acromion of scapula.
26. Anterior surface of scapula.
27. Head of humerus—Arm-bone.
28. Body of humerus.
29. Condyles of humerus.
30. Head of radius—Outer bone of forearm.
31. Body of radius.
32. Ulna—Inner bone of forearm.
33. Carpal ends of radius and ulna.
34. Ilium.
35. Anterior superior process of ilium.
36. Anterior inferior process of ilium.
37. Symphysis pubis.
38. Tuberosity of ischium.
39. Brim of pelvis.
40. Foramen ovale.
41. Head of femur or thigh-bone.
42. Neck of femur.
43. Trochanter major of femur.
44. Body of femur.
45. Condyles of femur.
46. Patella—Knee-pan.
47. Head of tibia—Thick bone on inner side of leg.
48. Body of tibia.
49. Base of tibia.
50. Fibula—Thin bone on external side of leg.

FRONT VIEW OF RIGHT HAND AND WRIST (Fig. 2).

1. Scaphoid bone.
2. Semilunar bone.
3. Cuneiform bone.
4. Pisiform bone.
5. Trapezium.
6. Trapezoid.
7. Os magnum.
8. Unciform bone.
9. Metacarpal bones of thumb and fingers.
10. First row of phalanges of thumb and fingers.
11. Second row of phalanges of fingers.
12. Third row of phalanges of thumb and fingers.

FRONT VIEW OF RIGHT FOOT (Fig. 3).

1. Superior articulated surface of astragalus.
2. Anterior portion of astragalus.
3. Os calcis—Heel-bone.
4. Commencement of groove of interosseous ligament.
5. Scaphoid bone.
6. Tuberosity of scaphoid bone.
7. Internal cuneiform bone.
8. Middle cuneiform bone.
9. External cuneiform bone.
10. Cuboid bone.
11. Metatarsal bones.
12. First row of phalanges of toes.
13. Second row of phalanges.
14. Third row of phalanges.

THE MUSCLES.

SIDE VIEW OF FULL FIGURE (Fig. 1).

1. Occipito-frontalis—Used to raise the eye-brows, wrinkle the skin of the forehead, and move the scalp backwards and forwards.
2. Temporalis—Helps to elevate the lower jaw.
3. Orbicularis palpebrarum—Closes the eyelids.
4. Masseter—Helps to elevate the lower jaw and move it forwards.
5. Sterno-cleido-mastoideus—A pair of muscles which together bow the head forwards; one acting by itself is able to turn the head and therefore the chin to the opposite side.
6. Trapezius—The trapezii muscles acting together draw the head directly backwards; one of them acting alone inclines the head to the corresponding side; the superior part of the trapezius raises the point of the shoulder; this muscle also aids in drawing the scapula backwards and forwards, and in causing it to ascend and descend.
7. Platysma myoides—Assists in depressing the angle of the mouth.
8. Deltoides—Raises the arm, and aids in carrying it backwards and forwards.
9. Biceps flexor cubiti—
10. Brachialis anticus— Act together in bending the forearm.
11. Triceps extensor cubiti—Antagonist of the two former; when the forearm is bent, the triceps, by drawing in the extremity of the ulna, is able to extend it on the humerus, and thus bring both parts of the limb into a right line.
12. Supinator radii longus—A flexor of the forearm.
13. Extensor muscles of thumb.
14. Extensor muscles of wrist.
15. Pectoralis major—
16. Latissimus dorsi— Conjointly with teres major these muscles lower the arm when it has been elevated. press the arm closely to the side, and pectoralis major will by itself carry the arm along the side and front of the chest.
17. Serratus magnus—Assists in advancing the scapula and elevating the shoulder.
18. Obliquus externus abdominis—
19. Rectus abdominis in its sheath— Co-operate with the other abdominal muscles in supporting the abdominal viscera, and by their contractile power act successively on them, on the thorax, and on the pelvis.
20. Glutæus medius—
21. Glutæus maximus— The glutæi act alternately on the thigh-bone and pelvis: 21, by the direction of its fibres, is fitted to draw the thigh-bone backwards, whilst it turns the whole limb outwards if it be kept extended: when the thighs become the fixed points, the muscles act on the pelvis, and assist in maintaining the erect position of the body.
22. Tensor vaginæ femoris—Renders the fascia tense, and turns the limb inwards.

23. Vastus externus—Contributes to extend the leg upon the thigh; the extensor muscles of the leg act upon the thigh-bone, and counteract the weight of the body, which tends to bend the knee and other articulations.
24. Biceps flexor cruris—Assists in bending the leg on the thigh, and in turning the limb slightly inwards and outwards.
25. Gastrocnemius—Along with the solæus this muscle forms the calf of the leg; they jointly draw on the heel-bone, lifting it from the ground, and cause the foot to represent an inclined plane.
26. Tibialis anticus—Co-operates with 31 in bending the foot on the leg; acting separately, each gives a slight inclination towards the corresponding side.
27. Extensor communis digitorum—Aids in extending the toes, and in bending the foot upon the leg.
28. Solæus—See 25.
29. Peronæus longus—
30. Peronæus brevis— } Act together in drawing the foot back, and so extending it on the leg.
31. Peronæus tertius—A flexor of the foot on the leg, co-operating with 26.
32. Abductor minimi digiti—Bends the little toe, and separates it from the others.
33. Extensor pollicis proprius—Extensor of the great toe; unites with 27 in bending the foot upon the leg.
34. Flexor communis digitorum—Bends the toes towards the sole of the foot.
35. Tendo Achillis—Formed by junction of tendonous expansions of 25 and 26; the strongest tendon in the body.

FRONT VIEW OF RIGHT ARM (Fig. 2).

1. Deltoides—See 8 of Fig. 1.
2. Pectoralis major—See 15 of Fig. 1.
3. Coraco brachialis—Smallest muscle of upper arm; assists in moving the arm forwards and upwards.
4. Biceps flexor cubiti—See 9 of Fig. 1.
5. Brachialis internus—Part of brachialis anticus; see 10 of Fig. 1.
6. Triceps extensor cubiti—See 11 of Fig. 1.
7. Pronator radii teres—Turns the palm of the hand downwards, and aids in bending the forearm on the arm.
8. Supinator radii longus—Acts as antagonist to pronator of hand (7), turning the palm upwards; it is also a flexor of forearm.
9. Flexor carpi radialis—Bends the wrist and becomes a flexor of the forearm.
10. Palmaris longus, and fascia—Bends the hand upon the forearm, and aids in its pronation.
11. Flexor digitorum communis—Bends the fingers towards the palm, acts on the wrist, and assists in the bending of the arm.

12. Flexor carpi ulnaris—Bends the wrist, and becomes a flexor of the forearm.
13. Abductor pollicis manus—Carries the thumb outwards and forwards from the palm.
14. Flexor brevis pollicis—Flexor of first joint of thumb.
15. Palmaris brevis—A small cutaneous muscle connected with the muscles of the little finger.

FRONT VIEW OF RIGHT LEG (Fig. 3).

1. Glutæus medius—See 20 of Fig. 1.
2. Tensor vaginæ femoris—See 22 of Fig. 1.
3. Psoas and iliacus—Bend the thigh on the pelvis, and rotate the limb outwards.
4. Pectineus—Contributes to bend the thigh-bone on the pelvis.
5. Adductor longus—one of the adductors of the thigh.
6. Sartorius—Bends the leg upon the thigh; it is known as "the tailor's muscle."
7. Gracilis—Acts along with adductor muscles of thigh.
8. Rectus femoris—
9. Vastus externus—
10. Vastus internus—

    Extend the leg upon the thigh; the rectus and sartorius (6) help to maintain the erect position of the body.
11. Biceps flexor cruris—See 24 of Fig. 1.
12. Insertion of ligament of patella into tibia.
13. Tibialis anticus—See 26 of Fig. 1.
14. Extensor communis digitorum—See 27 of Fig. 1.
15. Peronæus longus—See 29 of Fig. 1.
16. Gastrocnemius—See 25 of Fig. 1.
17. Solæus—See 28 of Fig. 1.
18. Peronæus brevis—See 30 of Fig. 1.
19. Abductor pollicis pedis—Abductor of great toe.

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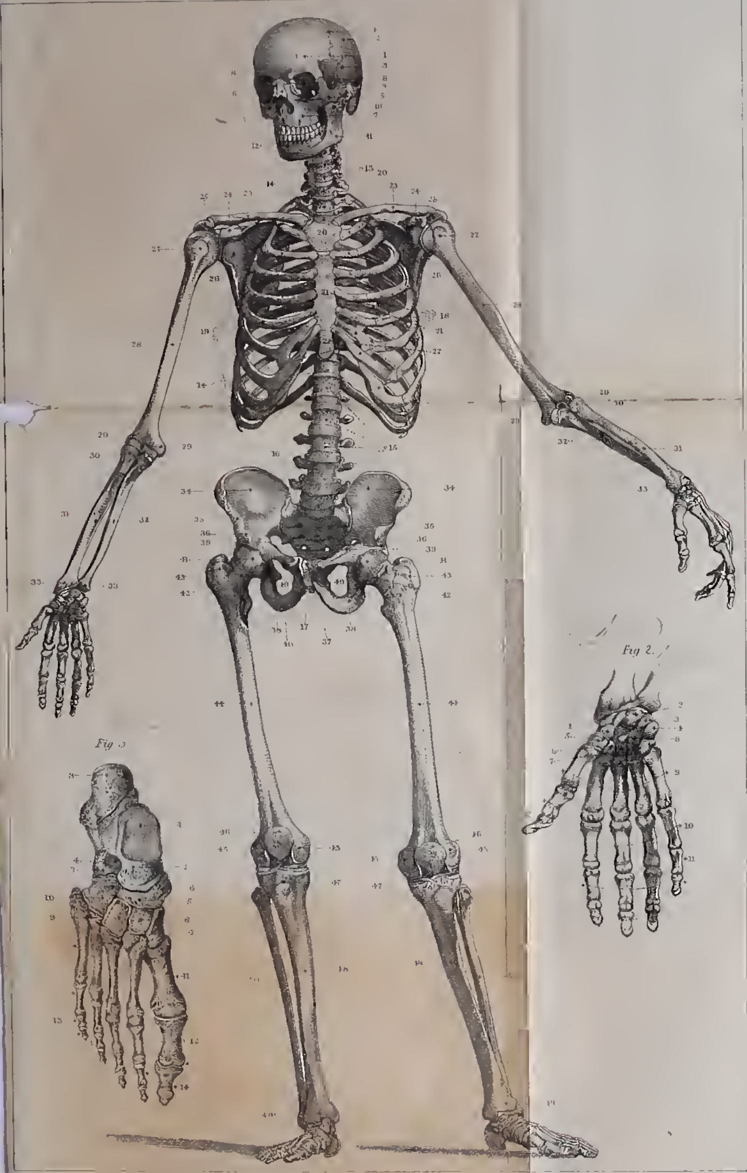

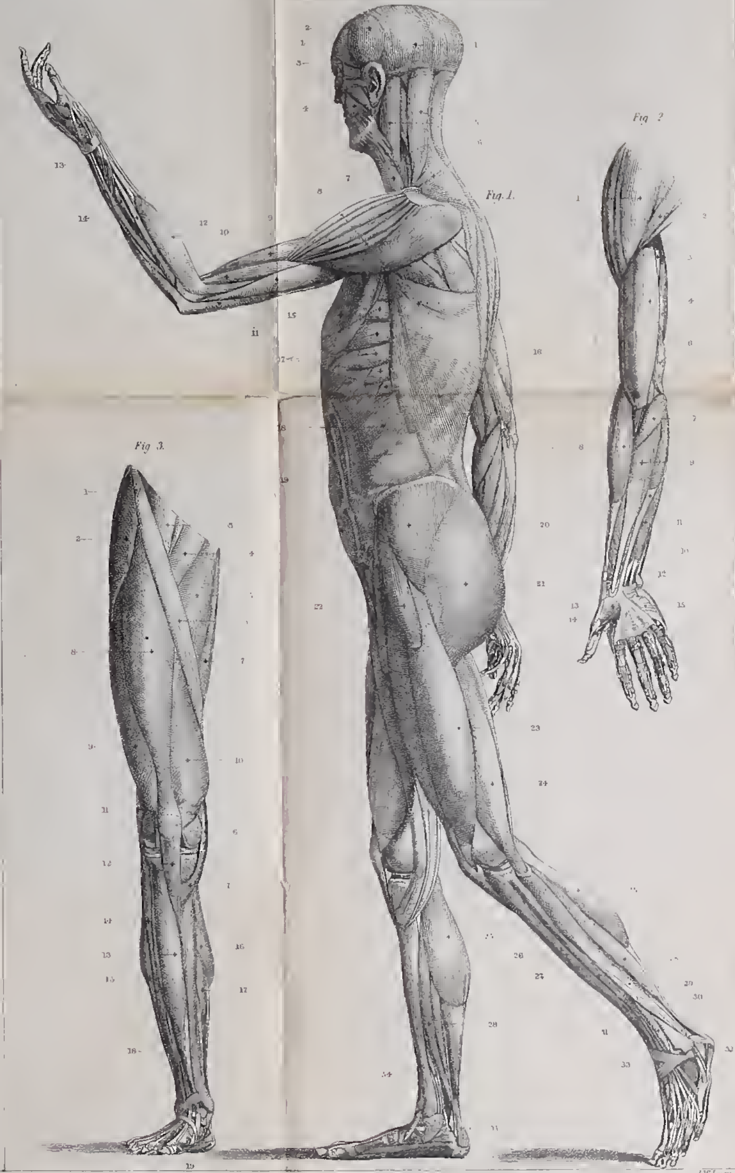

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